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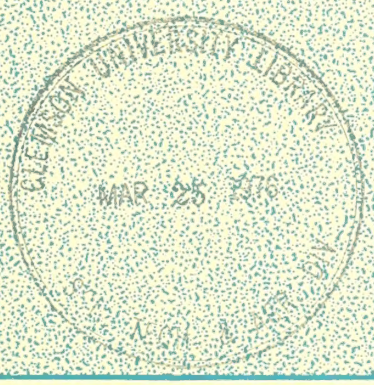
Softwood Log Exports and the Value and Employment Issues



David R. Darr

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. Department of Agriculture Forest Service Portland, Oregon

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SOFTWOOD LOG EXPORTS AND THE VALUE AND EMPLOYMENT ISSUES

Reference Abstract

Darr, David R.
1975. Softwood log exports and the value and employment issues. USDA For. Serv. Res. Pap. PNW-200, 13 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Direct employment per thousand board feet of logs processed is higher in domestic lumber and veneer and plywood industries than in the log export industry. Relative product values and indirect effects of domestic and export markets vary over time. Success of policies to maximize trade offs between markets is not certain because responses of industry members to changes in policies are uncertain.

KEYWORDS: Logging economics, export (forest products), employment (forest labor), trade policy (international).

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RESEARCH SUMMARY
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1975

Potential value and employment trade offs between the log export and domestic timber processing industries are issues when the effects of log export control policies are weighed. Value and employment trade offs are only part of the broader debate over softwood log exports.

Direct employment per thousand board feet of logs processed in Washington and Oregon in 1973 was 4.72 man-hours for the log export industry, 12.58 for the lumber industry, and 19.47 for the veneer and plywood industry. Relative values of products in the two markets vary over time. Relative export values were higher in 1970 and 1973; domestic values were higher in other years over the period 1965-73.

Indirect effects of the domestic and export markets on value and employment are tied to direct values created in the two markets and vary over time. Owners of stumpage have become relatively more important in determination of indirect impacts of the two markets on value and employment.

The success of policies to maximize trade offs between the domestic and export markets is not certain because the responses of industry members to changes in trade policies are uncertain. These responses will be constrained by market and foreign policy conditions at the time of a change in trade policy.

Introduction

Many issues have been raised in the continuing debate over softwood log exports. An understanding of these issues is necessary to place in proper perspective the positions of various individuals and groups affected by log exports. In particular, it is important that trade offs among interests are considered in proposed or potential legislation on control of log exports.

Two key issues in the debate over potential log export control legislation are the value and employment associated with exporting logs compared with domestic processing of similar logs. Identification of the trade offs between the export and domestic industries in value and employment is important because of the potential effects of legislation on Pacific Northwest and U.S. economies.

Trade offs between export and domestic industries in value and employment are only part of the information necessary for weighing alternative policies on log exports. An understanding of the development of the log export issue is necessary to keep in perspective information on the value and employment components of the issue.

The total economic impacts of the export and domestic industries can be broken down into direct and indirect impacts. This report presents quantitative information on only the direct impacts of the two industries. However, an understanding of how and what kinds of indirect impacts are transmitted to the Pacific Northwest and U.S. economies is necessary to keep in perspective information on the relative direct impacts of the two industries.

The purposes of this report are:

1. To discuss the development of the value and employment issues within the perspective of the broader debate over softwood log exports.

2. To compare direct value and employment associated with exporting vs. domestic processing of similar softwood logs.

3. To provide a background on the possible indirect effects of the export and domestic markets on value and employment in the forest products industries.

Development of Issues

THE LOG EXPORT ISSUE HAS DEVELOPED OVER THE PAST DECADE

Log export volume from the U.S. west coast increased steadily through the 1960's into the 1970's (fig. 1). Exceptions were a decline in 1969 attributable in part to a decline in demand in Japan and a decline in 1971 caused in part by a labor dispute which affected west coast shipping for 3 months. Total volume stabilized in 1973. From 1962 through 1973, Washington and Oregon accounted for over 85 percent of annual softwood log exports from the west coast.

After 1969, exports became increasingly concentrated in Washington and Oregon, as did the focus of the issues involved with this trade. By the 1970's, the log export market accounted for about 15 percent of the timber harvest in Washington and Oregon (fig. 2). The developing log export market added pressures to the timber resource market in the Pacific Northwest. These pressures tended to peak during periods of high domestic demand and led to the development of many proposals to limit forest products exports, including softwood logs. For example, the Morse Amendment, in effect from 1968 through 1973, limited softwood log exports from Federal lands west of the 100th meridian to 350 million board feet. Before its expiration in 1973, the Morse Amendment was superseded by a ban on softwood log exports from

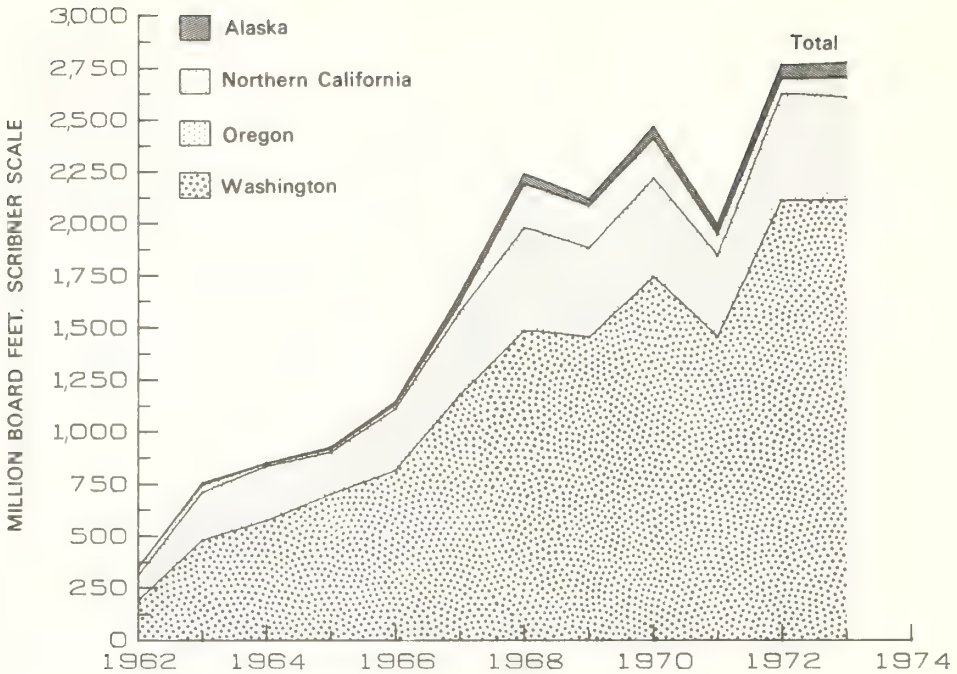

Figure 1.--Softwood log exports from the Alaska, northern California, Oregon, and Washington Customs Districts, 1962-73. Source: Ruderman (1975).

Figure 2.--Softwood log exports as a percent of timber harvest in Washington and Oregon, 1961-73. Source: Ruderman (1975).

Federal lands west of the 100th meridian; log exports from State of Oregon lands had been banned in 1961.

VALUE AND EMPLOYMENT TRADE OFFS ARE ONLY PART OF THE LOG EXPORT ISSUE

Policies to limit trade, including softwood log exports, involve trade offs. Arguments for and against log exports which have developed over the past decade are centered primarily on the impact of the export market on:

1. Price and availability of timber in the Pacific Northwest.
2. U.S. housing costs.
3. U.S. balance of trade.
4. U.S. trade and foreign policy.
5. Value and employment created in the export market compared with the domestic market.

It is not the intent here to either develop or evaluate these pro and con positions. Hamilton (1971) describes the nature of the trade offs involved in log export policy. The intent is to emphasize that value and employment associated with log exports compared with domestic processing comprise only part of the picture to be developed for evaluating trade offs between the two markets.

VALUE AND EMPLOYMENT TRADE OFFS DEPEND ON UNCERTAIN EFFECT OF EXPORT MARKET ON TIMBER AVAILABILITY

Lack of historical precedent prevents prediction of reactions of Pacific Northwest log producers and foreign consumers to a reduction in softwood log exports. Pacific Northwest log producers are only part of a "Pacific Rim" softwood supply-demand framework. Japan imports softwood products from British Columbia and the Soviet Union as well as from the Pacific Northwest States. The United States relies on British Columbia for softwood timber products. The Pacific Northwest forest products industries must compete with foreign producers for the Pacific Rim and other foreign markets. Within the United States, Pacific Northwest industries must compete with other regions for domestic markets.

Domestic and foreign producer and consumer options, in the event of reduction in U.S. softwood log exports, would be constrained by the market and foreign policy conditions at the time of the reduction. The options available at any given time in the future and reactions to these options cannot be predicted with certainty. How much of the log export volume would be processed domestically in the event of a reduction in exports will remain a major uncertainty in evaluations of value and employment trade offs between the two markets.

EXPORT VOLUME IS CONCENTRATED IN HEMLOCK; DOMESTICALLY PROCESSED VOLUME IS IN DOUGLAS-FIR

Although uncertainty surrounds any estimate of the volume of exported logs which might be processed domestically, available information on the species and grades of logs going into the two markets indicates that at least some of the volume going into the export market could be processed domestically. However, physical characteristics are only an indicator of potential and not a predictor. Log flows between the two markets are limited by relative economic conditions in the two markets, log supply constraints, and the objectives and capabilities of owners of stumpage and logs.

The following tabulation shows that log export volume was more concentrated in hemlock than was domestic volume in Washington and Oregon.

Percent of log consumption by species, 1972[1/]

Species	Sawmills	Veneer and plywood mills	Log exports
Douglas-fir	49.4	81.2	27.4
Hemlock	17.6	4.9	56.3
True firs	5.1	4.7	4.7
Spruce	.6	2.0	3.6
Western redcedar	4.0	1.2	4.9
Other species	23.3	6.0	3.1
Total	100.0	100.0	100.0
Total volume (thousand board feet, Scribner scale)	9,026,474	4,510,122	2,437,373

Douglas-fir was the most important species in total log volume consumed in the two domestic industries but accounted for only 27.4 percent of the total export volume in 1972.

Log export volume is concentrated in the No. 2 and Better saw-log grades:

Percent of sales by log grade, 1973[2/]

Grade	Water and inland	Export
Peeler	5.9	9.7
Special mill	6.6	22.4
No. 1 sawmill	.8	4.3
No. 2 sawmill	37.2	45.9
No. 3 sawmill	24.8	17.1
Cull, Utility, and No. 4 sawmill	17.7	.5
Ungraded	7.0	.1
Total	100.0	100.0
Total sales volume (thousand board feet, Scribner scale)	585,714	517,723

[1/] Sources: Bergvall and Ormrod (1974) and Schuldt and Howard (1974).

[2/] Source: Industrial Forestry Association (1974).

Compared with log export sales, domestic sales (water and inland) reported by the Industrial Forestry Association (1974) are concentrated in the No. 2 and lower quality saw-log grades.[3/]

POTENTIAL TRADE OFFS BETWEEN DOMESTIC AND EXPORT INDUSTRIES WOULD VARY WITHIN THE PACIFIC NORTHWEST

The impacts of a reduction in log exports would vary by local area within the Pacific Northwest. This should be considered in evaluations of trade offs between the two industries. For example, in 1972, log exports from the Olympic Peninsula of Washington amounted to 39.1 percent of the 2.4 billion board feet of logs consumed by the region's forest products industries (Bergvall and Ormrod 1974). By contrast, log export volume from northwest Oregon in 1972 amounted to 15.5 percent of total consumption of 2.4 billion board feet; for the rest of western Oregon, log exports amounted to 1.9 percent of total log consumption of 6.1 billion board feet (Schuldt and Howard 1974).

Available domestic processing capacity and other market constraints as well as the objectives of individual landowners are examples of the factors which would vary the trade offs between the two markets within the Pacific Northwest.

CYCLES IN THE EXPORT AND DOMESTIC MARKETS CAN CAUSE TRADE OFFS TO VARY OVER TIME

In the Pacific Northwest, log exports are now permitted only from private and State of Washington lands. Before 1973, log exports from U.S. Forest Service and Bureau of Land Management (U.S. Department of the Interior) lands were permitted under terms of the Morse Amendment. The following tabulation shows for 1972 that the two private landownership categories accounted for about 71 percent of total log export volume, and State lands, 20.8 percent.

Percent of log exports by landownership, Washington and Oregon, 1972[4/]

Ownership	Percent
Forest industry	59.8
Farmer and miscellaneous private	10.8
State of Washington[5/]	20.8
National Forest	7.8
Other public	.8
Total	100.0

In contrast, the sawmill and veneer and plywood industries in the two States depended on U.S. Forest Service and Bureau of Land Management lands for 50.4 percent of their log consumption.

One effect of the restriction on log exports from Federal and State of Oregon lands is a contribution to the development of two distinct markets for logs in the Pacific Northwest. Constraints on log flows, when combined with different building cycles in the United States and Japan, can lead to the development of different price levels for similar logs in the two markets. Softwood products processed from logs exported to Japan are used primarily for construction in Japan.

3/ Industrial Forestry Association data have the following shortcomings for comparing export and domestic markets but were judged to be reasonable indicators of differences between the two markets: (1) The data refer to sales which may not correspond with actual market of end use; (2) a higher proportion of export sales than of domestic sales is sampled; and (3) within a log grade, there may be a tendency for better quality logs to be sold to the export rather than to the domestic market.

4/ Sources: Bergvall and Ormrod (1974) and Schuldt and Howard (1974).

5/ Log exports from State of Oregon were banned in 1961.

Population, income, mortgage interest rates, mortgage money availability, and other cost components of housing are examples of factors which determine the demand for construction in the United States and Japan. These variables change over time and lead to cycles in construction demand. Only coincidentally would these variables at the same point in time have the same relative effect on construction in both countries.

The value of U.S. currency relative to Japanese currency fluctuates under the floating exchange rate system. Variations in the exchange rate between the two currencies can cause price variation in the log export market unrelated to other variables of log supply and demand.

Prices received for logs in the two markets determine the amount of money available to stumpage owners, log processors, and other industry members for investment or other expenditures which affect employment levels. Variation in prices over time causes variation in the direct and indirect trade offs in value and employment between the export and domestic markets.

Direct Value and Employment Associated with Log Exports Compared with Domestic Processing

LOG PRICES ARE CONSISTENTLY HIGHER IN THE EXPORT MARKET THAN IN THE DOMESTIC MARKET

Adams (1974) found that over the 1960's and into the 1970's, annual average prices of similar logs were higher in export than in the domestic market (fig. 3). The difference in price between the two markets increased sharply in 1972 and 1973. It is difficult to attribute this export market price increase to any particular set of factors. However, devaluation of the U.S. dollar relative to the Japanese

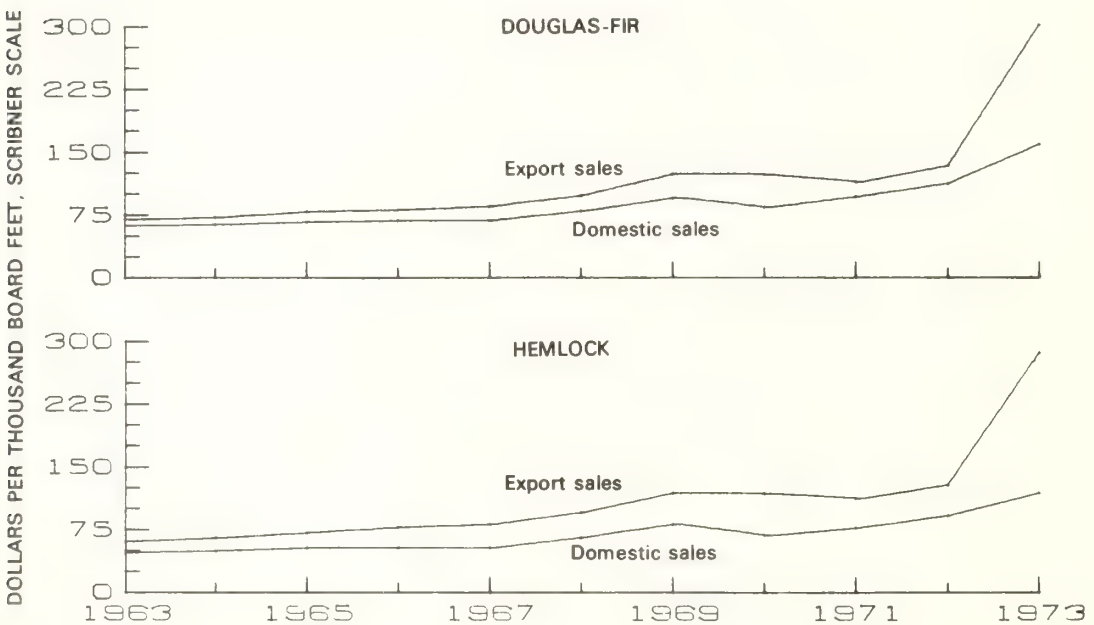

Figure 3.--Average prices for Douglas-fir and western hemlock No. 2 sawmill logs for export and for domestic sales, 1963-73. Source: Adams (1974).

yen and rapidly increasing demand in Japan apparently contributed to the jump in price.

Adams and Hamilton (1965) also found log prices to be higher in the export than in the domestic market.

PRICES FOR EXPORTED LOGS WERE HIGHER IN 1973 THAN THE VALUE OF LUMBER PRODUCED FROM SIMILAR LOGS; RELATIONSHIP VARIES OVER TIME

The relative contributions of the export and domestic lumber markets to the Pacific Northwest economy vary over time in direct value (table 1). The export product value per thousand board feet of a Douglas-fir No. 2 sawmill log in 1970 was nearly equal to the value of lumber and chips produced from similar logs; the export value exceeded the domestic value in 1973. Product values from domestic processing were higher in each of the other years from 1965 to 1973.

Relative export and domestic values for hemlock logs followed a pattern similar to that for Douglas-fir logs; the export value was higher in 1970 and 1973 but lower in each of the other years.

Domestic price controls are reflected in the price data for 1971-73. Although their effectiveness has been questioned (McKillop 1973), the intent of these controls was to dampen domestic prices; export prices were not controlled.

TABLE 1--*Product values of No. 2 Douglas-fir and hemlock sawmill logs in export market and in domestic lumber processing, 1965-73*

(Dollars per thousand board feet, Scribner scale)[1/]

Year	Douglas-fir		Hemlock	
	Export	Domestic	Export	Domestic
1965	93.70	124.82	71.00	96.36
1966	95.50	129.10	77.80	99.83
1967	100.00	130.52	81.70	100.52
1968	112.90	170.99	96.00	128.95
1969	138.80	173.84	119.30	137.73
1970	135.90	138.79	116.40	106.99
1971	127.30	182.95	110.50	140.27
1972	148.50	220.00	128.60	177.48
1973	319.10	284.98	287.40	231.09

[1/] Export values are for No. 2 sawmill logs. Domestic values are for 24-inch No. 2 sawmill logs which were considered representative. Domestic values include lumber and chips.

Sources: Export log price data from Industrial Forestry Association (1974); assumes $15 loading and handling charge each year except $18 for 1973. Domestic lumber processing data based on 1973 data from USDA Forest Service (1974), adjusted for changes in lumber prices.

DIRECT EMPLOYMENT REQUIRED PER THOUSAND BOARD FEET OF LOGS PROCESSED DECLINING IN BOTH THE DOMESTIC AND EXPORT INDUSTRIES

Technology, changing characteristics of the resource input, and the amount of equipment available for use by workers all influence the amount of labor required to process a thousand board feet of logs for the export or domestic market. These factors are reflected in figure 4 which shows that employment in logging, lumber, and veneer and plywood manufacture per thousand board feet of logs processed has tended to decrease in Washington and Oregon. Logging employment has gone from about 3.5 man-hours per thousand board feet in the early 1960's to about 3 man-hours in the 1970's; lumber, from 10 to less than 9 hours; and veneer and plywood, from 21 to 16.5 man-hours.

Employment required per thousand board feet in logging for the export market should approximate the trend shown for the domestic market in figure 4. Employment required for shiploading and log handling are the other two major components of employment in the log export industry. The following tabulation shows that employment in shiploading has gone from an average of 2.76 man-hours per thousand board feet in 1964 to less than 1 man-hour in 1973.

Man-hours required per thousand board feet, Scribner scale, to load logs for export[6/]

Type of operation	Average 1964	Average 1973
For special log ship:		
Large cranes (dockside)	2.03	0.90
Ship's gear	2.56	.83
For other ships:		
Large cranes (dockside)	2.69	(7/)
Ship's gear	3.76	(7/)
All types (average)	2.76	.85

6/ Sources: Adams and Hamilton (1965) and USDA Forest Service (data collected for Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 1974).

7/ No volume loaded.

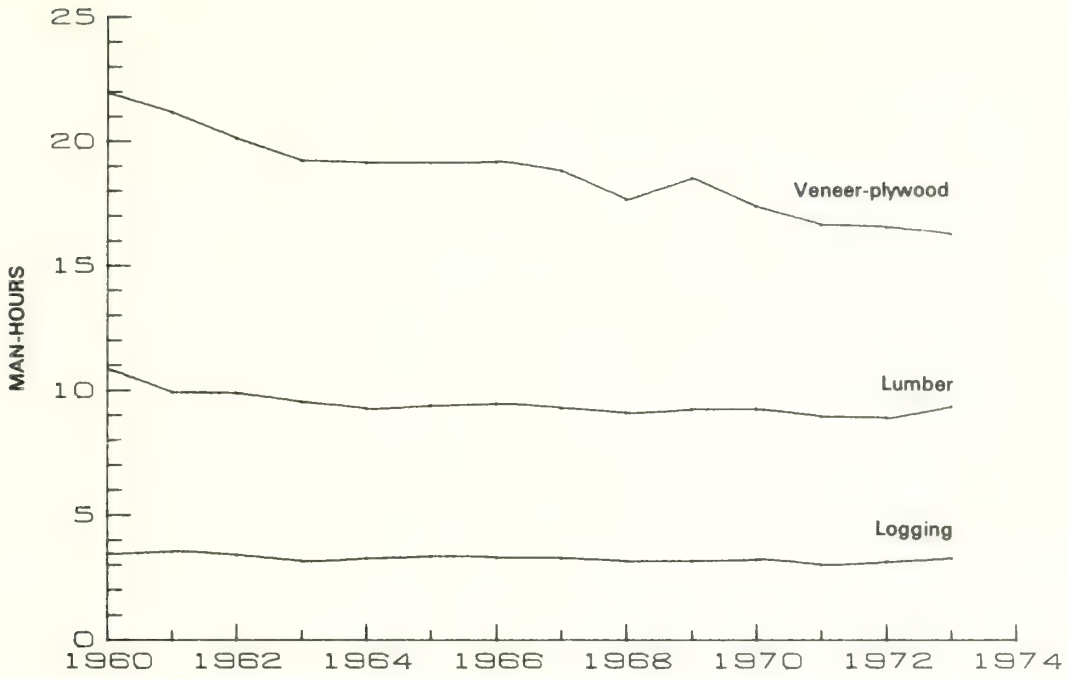

Figure 4.--Man-hours required per thousand board feet of logs processed in the logging, veneer and plywood, and lumber industries in Washington and Oregon, 1960-73. Source: Wall and Oswald (1975).

All the export volume in 1973 was loaded on special log ships which accounts for part of the decreased employment. Other employment in buying and selling, preparing, extra scaling, and rafting and towing of logs, and port operation, ship handling, and shipping agent services is difficult to measure but was estimated to have increased from 0.25 man-hour per thousand board feet in 1964 to 0.61 man-hour in 1973. This increase may in part reflect increased time for preparation and sorting of logs in 1973 compared with 1964.

DIRECT EMPLOYMENT REQUIRED PER THOUSAND BOARD FEET IS HIGHER IN DOMESTIC INDUSTRIES THAN IN THE EXPORT INDUSTRY

Direct employment per thousand board feet of logs processed for both domestic lumber and veneer and plywood manufacture was higher than for the export industry in both 1964 and 1973, as shown by the following tabulation:

Average man-hours of direct employment per thousand board feet of logs processed, Scribner scale[8/]

Industry	1964	1973
Log export	6.27	4.72
Lumber	12.44	12.58
Veneer and plywood	22.33	19.47

Employment in domestic lumber processing in 1973 was over two times

8/ Sources: Log export loading and ship and log handling data from Adams and Hamilton (1965) and USDA Forest Service (data collected for Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 1974); lumber, veneer and plywood, and logging employment data from Wall and Oswald (1975).

average employment in log exporting per thousand board feet of logs processed. Average employment in processing logs for veneer and plywood products was over four times average employment per thousand board feet of logs processed for the log export market.

Possible Indirect Effects of Export and Domestic Industries on Value and Employment

INDIRECT EFFECTS ARE TRANSMITTED THROUGH A MULTIPLIER EFFECT

Indirect impacts of the log export and domestic industries on value and employment in the Pacific Northwest occur when companies and their employees spend the money received for stumpage or timber processing. Recipients of the money spend it for things they need. The money continues to change hands, creating a multiplier effect. This effect stops when the money leaves the Pacific Northwest to buy imports from other areas.

From a national perspective, the money originating in the export and domestic forest products industries of the Pacific Northwest continues to generate value and employment as it circulates through other regions of the United States.

THE RECENT RISE IN STUMPAGE PRICES HAS INCREASED THE RELATIVE IMPORTANCE OF STUMPAGE OWNER AS A DETERMINANT OF INDIRECT ECONOMIC IMPACTS

Between 1970 and 1973, there was at least a threefold increase in stumpage prices on the major public landownerships in western Washington and western Oregon (table 2).

These prices are indicators of prices for stumpage purchased from private lands and a measure of the value of stumpage which is harvested from a mill's land and consumed by the mill. The costs of logging and processing have not increased to the same extent that stumpage prices have increased. Average appraised logging and processing costs for U.S. Forest Service sales in western Washington and western Oregon increased from $79 per thousand board feet in 1970 to $94 per thousand board feet in 1973 (USDA Forest Service 1970-73).

The rapid increase in stumpage prices has made the stumpage owner

TABLE 2--*Average stumpage prices for timber sold on public lands in western Washington and western Oregon, 1970-73*

(In dollars per thousand board feet, Scribner scale)

Area and public agency	1970	1971	1972	1973
Western Washington:				
U.S. Forest Service	30.06	25.53	56.44	105.61
State of Washington	52.15	46.42	77.65	202.01
Western Oregon:				
U.S. Forest Service	30.12	35.30	56.60	114.64
U.S. Bureau of Land Management	52.02	47.06	68.18	129.50
State of Oregon	35.52	36.76	64.15	120.55

Source: Ruderman (1975).

increasingly important in the indirect economic impact of the domestic and export industries on value and employment in the Pacific Northwest; these indirect impacts depend on how the stumpage owner spends his receipts.

Higher stumpage prices are an incentive for more intensive management of forest lands; higher prices in the export market increase this incentive. Whether or not increased stumpage receipts are used to intensify land management or for other purposes depends on the objectives and capabilities of individual landowners. Information is not available for the Pacific Northwest States on how receipts from higher stumpage prices are being spent nor on the extent of the multiplier effect on supporting industries. Individual and corporate landowners, who account for about two-thirds of the export and one-half of the domestic log consumption, have differing objectives and capabilities

AVAILABLE INFORMATION SHOWS OUTPUT MULTIPLIERS ARE SIMILAR FOR THE EXPORT AND DOMESTIC SAWMILL INDUSTRIES

The output multiplier measures the impact on total business sales in a region when an industry makes a $1 sale outside the region. Available information shows these output multipliers to be 2.47 for the logging industry, 2.45 for sawmills, and 2.1 for the plywood industry in the State of Washington (Business-Economics Advisory and Research, Inc. 1970) The multiplier for the logging industry should approximate the multiplier for the log export industry. For the logging industry, this indicates that $1's worth of logs exported from a Pacific Northwest State resulted in a total of $2.46 worth of business sales in the State. This total includes the original dollar of log exports. Multipliers for the other two industries are interpreted similarly.

These output multipliers are based on 1967 data and do not reflect any change in sales and purchase patterns which may have occurred after stumpage prices increased in 1972 and 1973.

POTENTIAL TRADE OFFS BETWEEN EXPORT AND DOMESTIC INDUSTRIES IN INDIRECT IMPACTS DEPEND ON WHETHER EXPORTED LOGS WOULD HAVE BEEN PROCESSED DOMESTICALLY

Comparison of direct values created in the two markets indicates that differing business cycles cause these values to vary over time. For any one year, the direct value of lumber or plywood produced from logs might exceed the value of logs in the export market and vice versa. If the output multipliers which measure the economic impact per dollar of sales are equal, the market which creates the highest direct value per thousand board feet of logs processed would have the highest total economic impact in the Pacific Northwest per thousand board feet.

Indicated trade offs between these two markets would be realized only if logs to be exported would instead be processed domestically and vice versa. As has been previously discussed, the extent of movement of logs between these two markets in the event of a downturn in one of the markets will remain an uncertainty when other policies to maximize trade offs are weighed.

Summary

The continuing debate over national trade policies for softwood log exports is based on many issues which have developed over the last decade. Policy formulation is based on a weighing of these issues through the political process, and an understanding of the trade offs implied by different policies is necessary for proper perspective of the positions of various individuals and groups affected by log exports. Possible value and employment trade offs between the domestic and export markets are of interest for purposes of policy formulation because of the possible impacts on the Pacific Northwest and U.S. economies if log exports were curtailed

through legislation. Individual policymakers may weight these trade offs differently when evaluating them relative to trade offs implied in other issues.

This report has shown that the direct employment required to process a thousand board feet of logs is higher in the domestic lumber and veneer and plywood industries than in the log export industry. Constraints on log flows, floating exchange rates on currency, and different cycles in the demand for logs in Japan and the United States have caused development of different business cycles in the export and domestic markets. These cycles cause relative product values per thousand board feet of logs processed in the two markets to vary over time. Relative to the domestic lumber industry, export values tended to be higher in 1970 and 1973; domestic product values were higher in other years over the period 1965-73.

Indirect effects of the two markets are tied to the money received by industry members for products processed in the two markets. These receipts determine the investment levels and other expenditures which affect value and employment in supporting industries. The amount of the indirect effects flowing from the two markets varies over time according to cycles in the markets.

Available information shows output multipliers for the log export, lumber, and veneer and plywood industries to be within a range of 2.1 to 2.5. However, information is not available on how private stumpage owners are spending receipts from an increase in stumpage prices. About two-thirds of exported logs and one-half of logs consumed by domestic industry originate on private lands.

Potential value and employment trade offs between the two markets vary over time. Whether policies to maximize these trade offs would be successful depends on whether industry members could and would shift logs from one market to another in response to policy changes. Industry members' responses to changes in export policies cannot be predicted with certainty. Uncertainty surrounding these responses will continue to add uncertainty to estimates of trade offs between the export and domestic markets.

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1976
USDA FOREST SERVICE RESEARCH PAPER PNW-201

RESULTS OF Shelterwood Cutting in Western Hemlock

RICHARD L. WILLIAMSON
ROBERT H. RUTH

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE · FOREST SERVICE
PORTLAND, OREGON

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Results of Shelterwood Cutting in Western Hemlock

Reference Abstract

Williamson, Richard L., and Robert H. Ruth
1976. Results of shelterwood cutting in western hemlock. USDA For. Serv. Res. Pap. PNW-201, 25 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Twelve shelterwood densities, ranging from 38 to 235 square feet of basal area per acre, were created in a 60-year-old stand. Eleven years after the first cut, regeneration was heavily overstocked under all densities. Brush was adequately controlled by overstory densities of at least 90 square feet of basal area. Overstory volume growth per acre during the regeneration period was approximately proportional to number of trees. Based on clearcutting experience on similar western hemlock sites, shelterwood harvesting probably was not essential for successful regeneration at this location. However, shelterwood cutting is a viable alternative to clearcutting for harvesting and regenerating western hemlock.

KEYWORDS: Shelterwood cutting method, western hemlock, silvicultural systems, natural regeneration.

RESEARCH SUMMARY

Research Paper PNW-201

1976

A test of three-stage shelterwood harvesting in 60-year-old western hemlock established 12 overstory densities, ranging from 38 to 235 square feet per acre (8.7 to 54.0 m^2 per ha) after the first cut. All overstory densities resulted in overstocking, with numbers of seedlings averaging 650 per acre (1,600 per ha) after the first cut; ranging from 1,100 to 24,400 per acre (2,700 to 60,300 per ha) after the second cut; and from 8,500 to 26,700 per acre (21,000 to 66,000 per ha) after the final cut.

The extremes of treatment resulted in lower numbers of seedlings than resulted from intermediate treatments. Numbers were lowest under the densest overstory stands after the second cut, and lowest under the most open stands after the third cut.

Seedling height at the end of the study period increased as overstory density decreased.

Overstory trees showed no response to release in cubic-foot-volume growth, making stand growth approximately proportional to number of trees in the overstory.

Brush competition was not a serious problem in this area, averaging only 32-percent canopy density during the study. It appears, however, that the greatest densities of lesser vegetation that did occur under open stands inhibited

height growth of hemlock seedlings somewhat.

Since most land managers will opt for a two-stage harvest, regeneration results are also described after the second cut so that some idea of two-stage harvest results may be gained.

The shelterwood harvest system offers the land manager some flexibility from the standpoint of both securing regeneration and minimizing environmental impacts. Further flexibility is provided because land managers can clearcut or shelterwood harvest and be reasonably sure of adequate regeneration.

Introduction

The shelterwood system of establishing regeneration under the protection of the mature forest seems a logical harvest method for western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Hemlock is very shade tolerant, its seed germinates on the forest floor, and seedlings establish readily in the understory of a forest stand (Berntsen 1958). Nevertheless, clearcutting is the usual method of harvesting in the western hemlock type. Vast stands of second-growth hemlock that came in after clearcutting was done about the turn of the century attest to the general success of clearcutting.

Occasionally, however, problems arise in securing regeneration. These usually involve red alder (*Alnus rubra* Bong.) and brush encroachment, or locally severe site conditions. These problems should be less important under residual overstories after shelterwood treatment. Also, repeated thinning of young stands promotes seedling establishment in the understory. This condition points directly to shelterwood cutting as a logical harvest method (Ruth 1974). Finally, the burgeoning importance of esthetic appeal promotes a partial cutting harvest method in areas commonly in the public view.

Shelterwood characteristics in young-growth western hemlock were studied on the Hemlock Experimental Forest[1/] near Hoquiam in western Washington. The objective was to evaluate shelterwood cutting for regenerating western hemlock on coastal sites. Study establishment was reported earlier (Herman 1962), and subsequently, a synopsis of interim results was published (Williamson 1966). This final report summarizes results 2 years after overstory removal (11 years after the first cut).

[1/] Maintained in cooperation with St. Regis Paper Company, Tacoma, Washington.

The Study Area

In 1960, before cutting, the 70-acre (28-ha) study area supported a well-stocked almost pure western hemlock stand about 60 years old. A few older trees, residual from old-growth logging, were scattered throughout the area. Hundred-year site index is estimated at 157 feet (48 m); cubic and Scribner volumes in 1960 averaged 8,700 cubic feet and 43,000 board feet per acre, respectively (609 m^3 per ha). Average number of 6-inch (15-cm) d.b.h. and larger trees per acre was 274 (677 per ha), and their quadratic mean d.b.h. was 12 inches (30 cm). Trees smaller than 6-inch d.b.h. were generally scattered throughout the area. They were considered to be advance regeneration, and most were destroyed during logging.

The soil is Hoquiam clay loam having large soil moisture storage capacity.[2/] The soil is deep and is derived from marine sediments.

Methods

PLOT LAYOUT

The 70-acre (28-ha) study area was divided into 12 compartments of approximately 6 acres (2.4 ha) each. A different treatment was applied to each compartment. Detailed measurements were made on a central acre in each compartment, except for two treatments where topography required two 1/2-acre (0.2-ha) tracts each (S-4 and S-5 in fig. 1). Within each acre, 24 to 26 one-milacre plots were established on a systematic grid. Details of data collection and analysis are in the appendix.

[2/] Robert F. Tarrant. Geology and soil characteristics of the Hemlock Experimental Forest. Unpublished report on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 1954.

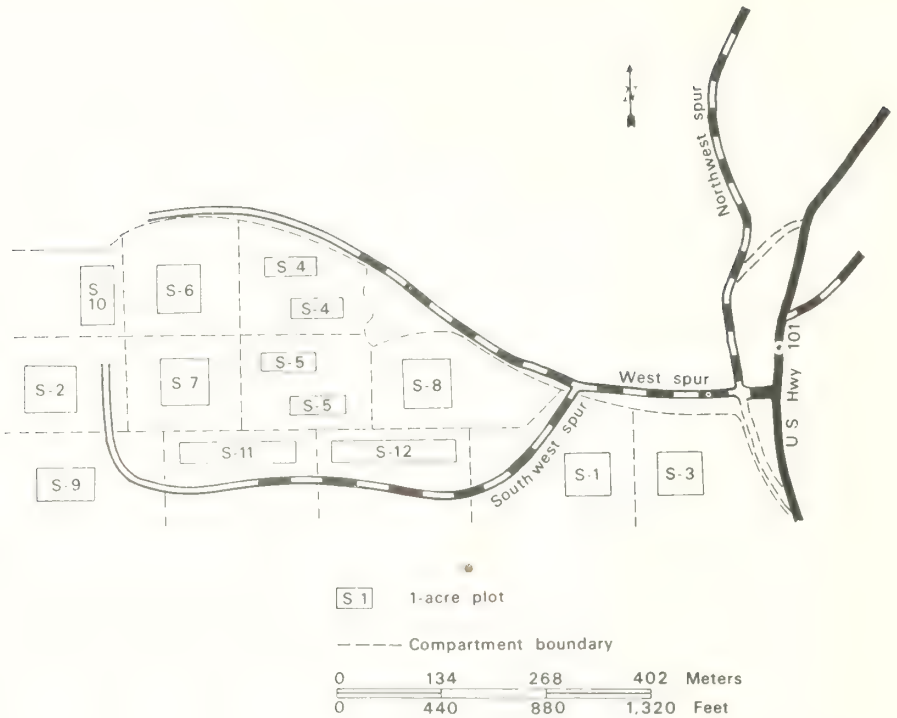

Figure 1.--Map of compartments and central acres containing milacre plots, shelterwood study area, Hemlock Experimental Forest.

TREATMENTS

Treatment was defined as number of residual overstory trees (6-inch d.b.h. and larger) per acre. A three-stage shelterwood cut was planned. The first and second cuts in 1960-61 and 1964-65, respectively, resulted in the following stand characteristics:

Plot	Trees per acre		Basal area per acre	
	1960-61	1964-65	1960-61	1964-65
			(Square feet)	
S-1	328	175	210	137
S-2	185	110	235	158
S-3	135	97	185	159
S-4	134	65	196	117
S-5	145	62	121	64
S-6	90	40	162	74
S-7	54	27	84	73
S-8	58	18	82	44
S-9	68	40	59	52
S-10	64	21	72	36
S-11	32	17	38	43
S-12	42	20	48	19

Basal area per acre is the average of estimates made at each milacre plot with a 30 basal-area-factor prism. This average, hereafter, is referred to as BA30. The third cut was in 1968 and 1969.

The range in stand and forest floor conditions as of 1964 is illustrated in figure 2.

The second cut was originally scheduled to begin in 1965, but sufficient windfall occurred in a severe windstorm in October 1962 to advance this cut to 1964 to prevent decay losses. Some treatments were not cut until 1965. Thus, the interval between the first and second cuts for the various treatments varied between 2.5 and 4 growing seasons. The second cut reduced numbers of trees by approximately one-half. The third cut was final overstory removal.

Harvesting of the first cut in 1960-61 was by crawler tractor. The harvesting in 1964-65 and 1968-69 was by rubber-tired skidder (fig. 3).

Figure 2.--Dense stands like A have a forest floor like B. More open stands, C, encourage seedling establishment, D. The most open stands, E, support a mat of vegetation, F.

Figure 3.--Logging on the shelterwood study area, 1964.

Results

This study was designed for a three-stage shelterwood harvest. The primary emphasis in this section, therefore, will be on results after completion of these three stages. We recognize, however, that in practice, most land managers will opt for a two-stage harvest. Therefore, after looking at regeneration by 1971, 2 years after the final cut, we will examine the status of regeneration after the second cut, pretending that we are looking at results of a two-stage harvest. A real two-stage harvest, however, would result in more slash and in more skidding than occurred at the second cut in this study. These factors would tend to lower somewhat the number of seedlings compared with the numbers that actually occurred after the second cut.

Finally, we will tell what happened to the overstory and to lesser vegetation.

The number and distribution of hemlock seedlings needed for a new stand depend on management objectives. Current practice in precommercial thinning of western hemlock is usually to thin to a 12- by 12- (3.6- by 3.6-m) or a 10- by 10-foot (3.0- by 3.0-m) spacing, 302 and 436 trees per acre (746 and 1,077 per ha), respectively. Theoretically, those stocking levels would result if 30.2 or 43.6 percent of the milacre plots are stocked with one established seedling. Practically, many plots will have more than one seedling. Some extra seedlings will be needed, however, because mortality will occur. Some seedlings will become established on poor microsites and grow slowly, and some will be genetically inferior. Each manager must set his own stocking objectives.

Hemlock regeneration over 0.3 foot (9 cm) tall is reported here as a percent of milacre plots stocked and as number of seedlings per acre. Numbers after 1964 are conservative, particularly at the higher levels, because of the difficulty of mapping more than 10 seedlings on a milacre quadrant (one-quarter of a milacre). Numerous quadrants eventually had more than 10 seedlings.

REGENERATION BY 1971, 2 YEARS AFTER THE REMOVAL CUT

Number of Seedlings

At the beginning of the experiment, hemlocks averaged 2,220 advance regeneration stems per acre (5,485 per ha) over all treatments. The first cut destroyed many of these, leaving 650 per acre (1,606 per ha) 1 year later. Thereafter, seedling numbers decreased gradually from natural mortality and logging damage. In 1971, at the end of the experiment, 280 seedlings per acre (690 per ha) survived, 13 percent of the original number. The decrease in number of seedlings did not seem to be correlated with overstory density.

Hemlock postlogging regeneration was prolific (fig. 4). Many small seedlings became established the first year after the first cut. Of these, an average over all treatments of 440 per acre (1,087 per ha) already exceeded the minimum measurement height of 0.3 foot (9 cm). By 1964, there were over 12,200 hemlock seedlings per acre (30,200 per ha). After the second cut, the number was down a little more than 6 percent to about 11,500 per acre (28,400 per ha). Just before the final removal cut in 1968-69, the number of seedlings had increased to about 17,000 per acre (42,000 per ha). The final harvest did not destroy many seedlings, and the number had increased to over 18,500 per acre (45,700 per ha) by the final measurement in 1971.

Figure 4.--Shelterwood treatment S-12 was the poorest environment for seedling establishment. The first cut left an overstory basal area of 48 square feet per acre (11 m^2 per ha). The second cut, after four growing seasons, reduced basal area by one-half.

(A) Eight growing seasons after the first cut and just before the final cut, the average height of the tallest postlogging seedling per milacre was 4.0 feet (1.2 m).

(B) One growing season after the final cut there were 6,270 postlogging seedlings per acre (16,500 per ha), and the average height of the tallest seedling per milacre was 4.5 feet (1.4 m).

(C) Three growing seasons after the final cut there were 8,500 postlogging seedlings per acre (21,000 per ha), and the average height of the tallest seedling per milacre was 6.4 feet (2.0 m).

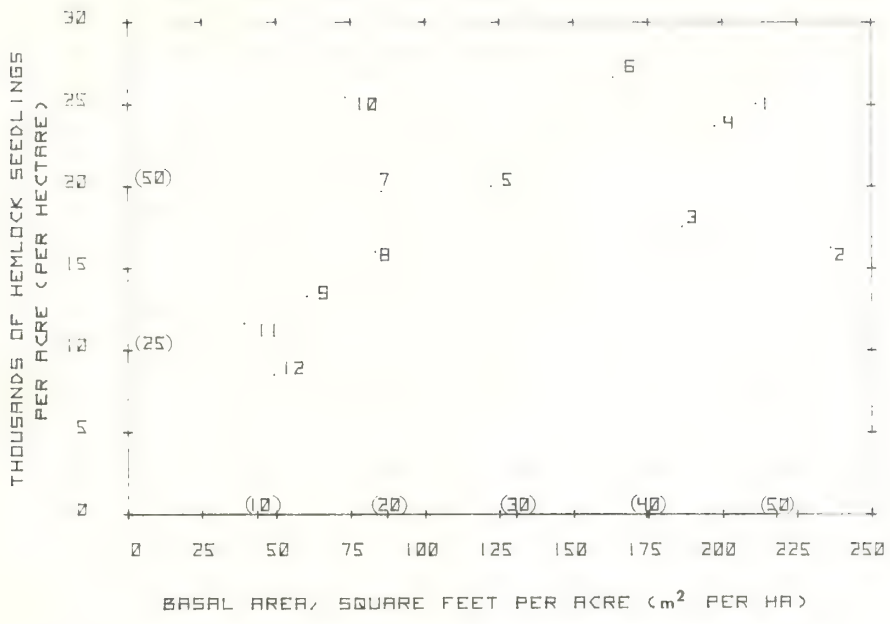

Figure 5.--Number of postlogging hemlock seedlings in 1971 by residual basal area per acre after 1960-61 cut, by treatment number.

The number of seedlings increased with residual basal area per acre of the overstory, then trended downward under the densest overstories (fig. 5). This relationship was not evaluated statistically because of bias resulting from not counting more than 10 seedlings per milacre after 1964. Fewer seedlings were established on the more open areas, probably because of more slash covering acceptable seed beds and more brush competition. Also, many seedlings were killed during germination and early establishment, presumably by solar radiation. The greatest number of seedlings became established under the moderate overstories of 100 to 190 square feet of basal area (23 to 44 m^2 per ha).

But even the lightest overstory of 38 square feet per acre (8.7 m^2 per ha) basal area had about 11,650 seedlings per acre (28,800 per ha)--too many for intensive management without costly precommercial thinning. The shelterwood system did too good a job of seedling establishment. This might have been expected, because clearcutting, which provides no overstory shelter, also frequently leads to overstocking. It might have been better if more seedlings had been destroyed during overstory removal.

One might expect several factors besides overstory density to influence seedling density. These include seed supply, logging damage, seed bed conditions, and illumination as influenced by both the overstory and lesser vegetation.

SEED SUPPLY

Apparently, more than adequate seed fall occurred in all treatments to satisfy regeneration opportunities that occurred. Average annual seed fall in the most open stand averaged nearly 1,000,000 viable seeds per acre (2,471,000 per ha) per year.

Average annual viable seed production per acre through the seed year 1965-66 (fig. 6) is related to BA30 as follows:

Number viable seeds (thousands)
= 904 + 5.071(BA30)
(r = 0.82 with 10 degrees of freedom, Sy.x ≒ 239.7)

There is no suggestion of curvilinearity in the data, indicating that a square foot of basal area in lower crown class trees supported as much seed production as in upper crown class trees. Below about 150 square feet per acre (370 m^2 per ha) of residual basal area, stands contained mostly dominant and codominant trees. Above this level, increased residual basal area meant more intermediate and suppressed trees in the stand.

LOGGING DAMAGE

Logging alone did not significantly reduce average density of seedlings. Seedlings destroyed during logging were mostly in main skid roads which cover a small percentage of the total area. Off the skid roads, yarding only a turn or two of logs over a small, limber seedling often mashed it into the duff or mud, but usually it returned to an erect position by the end of the next growing season.

SEED BED CONDITIONS

Condition of seed bed was not a significant factor in determining numbers of seedlings, perhaps because of the difficulty of quantifying the data, but more probably because average seed bed conditions did not differ significantly among treatments. Further, seed bed effects were strongly influenced by variations in density of the overstory. Deep slash, of course, strongly inhibited seedling establishment.

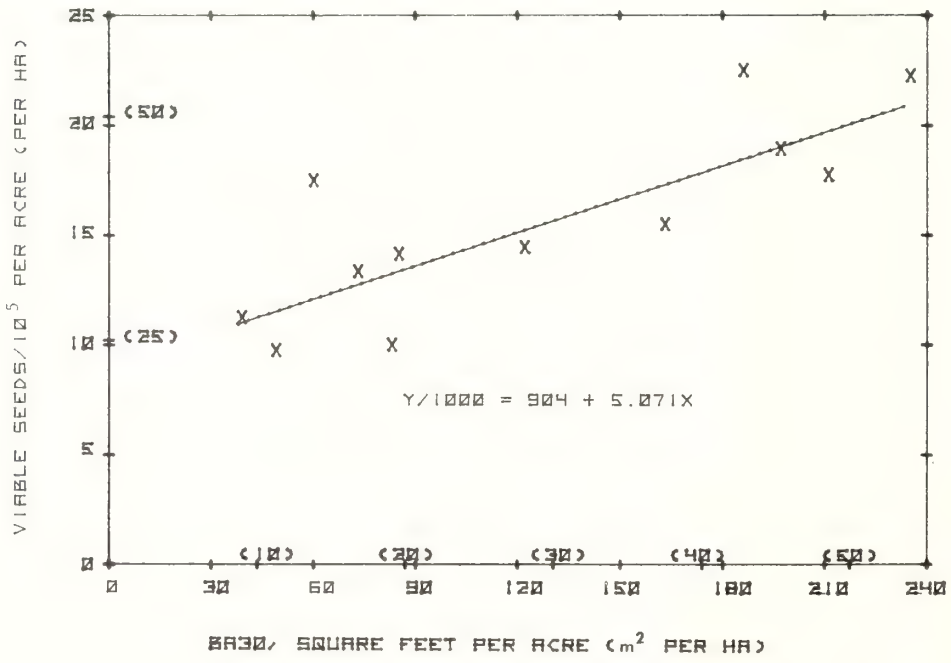

Figure 6.--Average annual (1961-65) viable seed production relative to residual basal area (BA30).

ILLUMINATION

Measurements of solar illumination showed that high numbers of seedlings occurred on some plots receiving only about 2 percent of full sunlight. Other factors, such as soil moisture and soil-air interface temperatures, probably interact with and modify the effects of illumination. Certainly, regeneration will not be suppressed by lack of illumination under any shelterwood stand which results from cutting at least one-third of the original basal area.

Stocking

Before any logging, 39 percent of the milacre plots under the 60-year-old stand were already stocked with at least one advance hemlock seedling. Disturbance during the first cut destroyed many of these seedlings, reducing the stocking 1 year later to 19 percent of the plots. Thereafter, stocking was reduced gradually by logging and natural mortality until only 10 percent of the milacre plots were stocked with advance regeneration at the end of the experiment. The range among the treatments was 0 to 24 percent. The decrease in stocking over time did not seem to be correlated with overstory density; a regression of final stocking on overstory density after the seed cut was not significant.

Postlogging regeneration over 0.3 foot (9 cm) tall was found on 12 percent of the milacre plots 1 year after the first cut. Stocking increased rapidly to an average of 80 percent over all treatments after the fourth growing season, then increased more slowly to 94 percent at the end of the experiment. The range among treatments was 84 to 100 percent of milacres stocked. There was no significant relationship between overstory density, expressed as basal area per acre after the first cut, and percent of milacres stocked with postlogging regeneration.

Height Growth

In 1960, height of the tallest advance seedlings under the dense uncut stand averaged 1.5 feet (47 cm) tall. At the end of the experiment in 1971, they averaged 7.4 feet (226 cm) tall. All three cuts destroyed some seedlings. Enough survived on eight treatments, however, to calculate regressions showing trends in total height with time and with overstory basal area. Since measurements were repeated on the same plots, statistical tests of significance are not valid and the regressions show general trends only. There was a drop in height after the first cut. This resulted from a reduction in average height when the tallest seedling on a milacre was destroyed during logging and replaced by a shorter one. After subsequent timber cutting, height growth exceeded losses due to replacement on the milacres, and the curves trended upward. Generally, height growth was greater on the treatments with less overstory density (fig. 7). Obvious exceptions to this trend are treatments 3 and 7, with 7 appearing lower than it should, and 3 appearing higher. Tallest seedlings on treatment 7 had much mortality, while those in treatment 3 experienced little, if any, mortality. The difference in height points out a potential advantage in preserving advance regeneration. Even though seedlings in treatment 7 were growing faster than those in treatment 3 at the end of the study, they were still about 2 feet (60 cm) shorter. After the final cut, height growth should be about the same in all treatments, so seedlings in treatment 7 probably will never catch up to those in treatment 3.

Postlogging regeneration reached the minimum measurement height of 0.3 foot (9 cm) soon after the first cut. As with advance regeneration, height growth

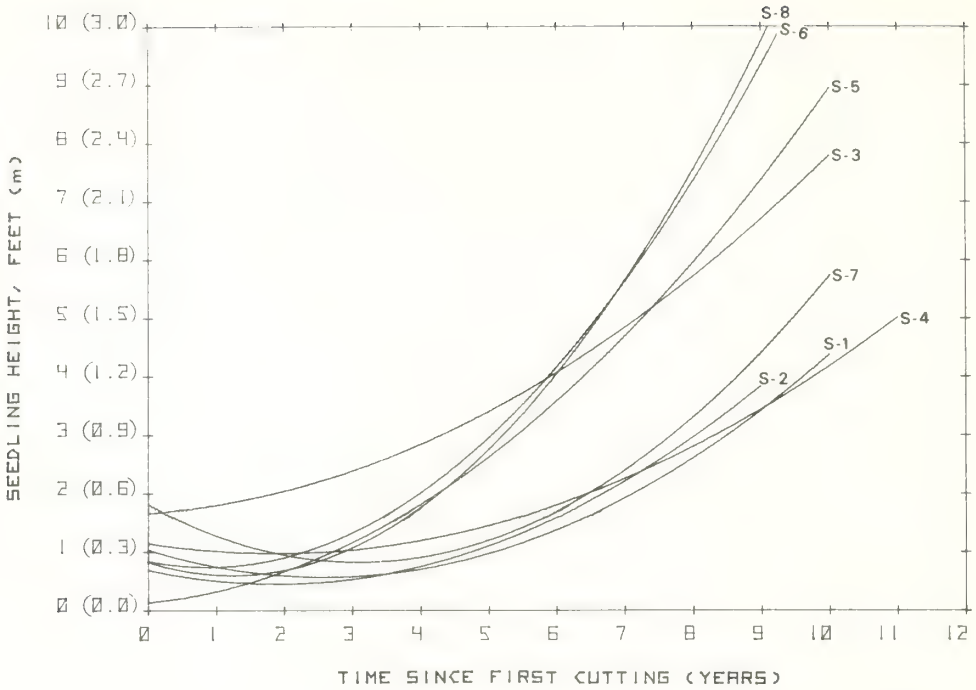

Figure 7.--Influence of time after cutting on heights of advance regeneration, tallest seedling per milacre, by treatment number.

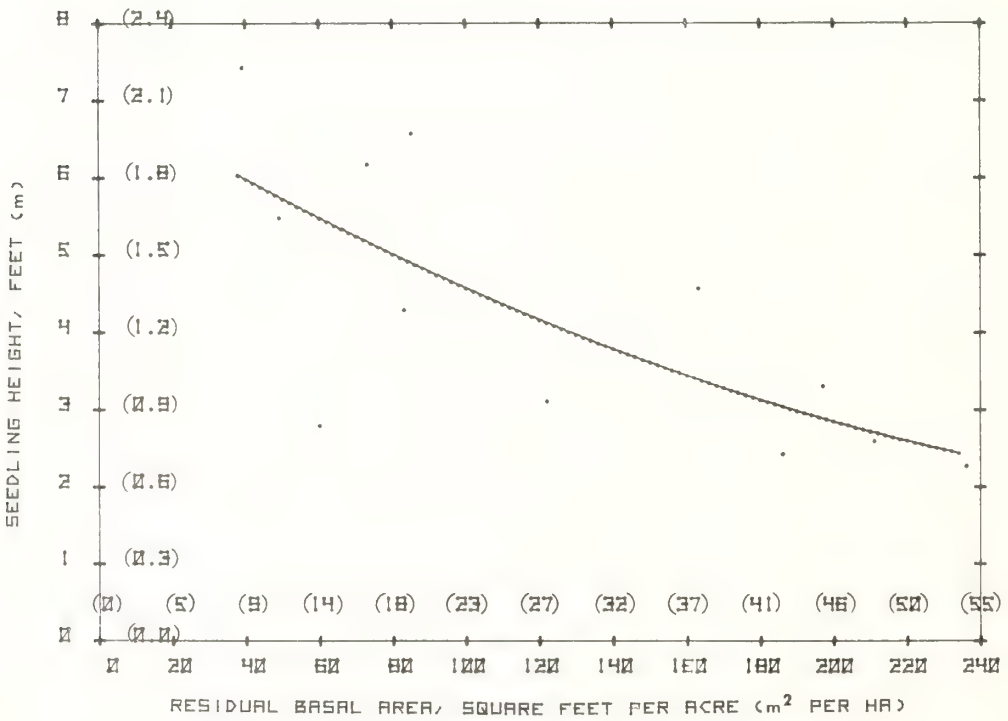

Figure 8.--Relationship of height of postlogging regeneration to overstory basal area per acre, 10 years after the first cut.

generally was greater on treatments with less overstory density (fig. 8 and 9).[3/]

Where marked deviations from the trend in figure 8 occurred, they could be attributed to differences in competing vegetation on the plots. Average height of the tallest seedling per milacre at the end of the experiment in 1971 was 4.6 feet (141 cm), about two-thirds as tall as the advance regeneration.

Figure 9.--Height of post-logging hemlock regeneration was greater on treatment areas with low overstory density.

(A) Treatment S-1. Basal area of the overstory after the first cut was 210 square feet per acre (48 m^2 per ha). Average height of the tallest seedling per milacre 10 growing seasons later was 2.7 feet (0.8 m).

(B) Treatment S-11. Basal area of the overstory after the first cut was 38 square feet per acre (8.7 m^2 per ha). Average height of the tallest seedling per milacre 10 growing seasons later was 7.6 feet (2.5 m).

[3/] The curve depicted in figure 8 is described by the equation:

Height (ft) = 7.1-0.0291(BA30)+0.00003948$(BA30)^2$

r = 0.727 with 9 degrees of freedom

($p < 0.05$)

REGENERATION BY 1965— SIMULATING A TWO-STAGE HARVEST

Because logging costs would be less, some land managers may want to use a two- rather than a three-stage harvest. Looking at regeneration after the second cut gives some idea how a two-stage shelterwood would work.

Number of Seedlings

After the second cut, the lowest number of postlogging seedlings was found in the stands which were densest after the first cut (fig. 10). The first cut in these stands approximated a moderate thinning, leaving the residual overstory dense enough to suppress most germinants. Numbers of seedlings increased as overstories became less dense and finally declined under the most open stands. For holding down precommercial thinning costs, building up stand density toward the end of a rotation might be a rational course of action.

The equation in figure 10 implies that steeper slopes have fewer seedlings than gentler slopes in this study where average slopes ranged from 0 to 30 percent. No reasons for this relationship are apparent, and it may be due to a concentration of steeper slopes at the extremes of treatment.

Stocking

Summing up the regeneration characteristics of these shelterwood treatments as of 1965, seedling density and stocking are at least adequate by almost any criterion. At the extremes of treatment, about 16 percent of the milacre plots were unstocked. This percentage of unstocked plots might be expected with over 1,000 seedlings per acre (2,500 per ha), considering that some clumpiness is bound to occur.

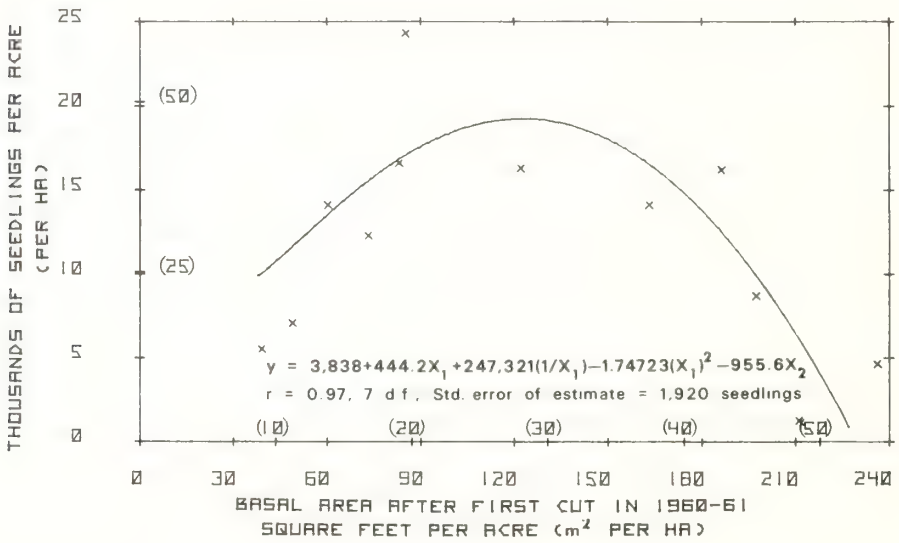

Figure 10.--Number of established seedlings 4 to 5 years after the first cut by residual basal area (X_1) and for average slope (X_2) of 15.5 percent.

TREATMENT EFFECTS ON OVERSTORY CHARACTERISTICS

Windthrow

Windthrow due to the October 1962 windstorm was remarkably light, considering that western hemlock has been observed to be a windthrow-prone species (Ruth and Yoder 1953), yet it was heavy enough that the second cut was advanced 1 year. One might expect all newly exposed trees, some almost completely isolated, to be blown down by a record windstorm. However, average basal area loss on the 1-acre plots was only 13 percent, ranging from 0 to 39 percent. Losses generally were heavier on the more open stands, but topography appears to have strongly modified the effects of cutting intensity. The worst loss (39 percent) occurred in a highly exposed area with 107 square feet of basal area per acre (24.5 m^2 per ha). Another area, relatively protected and with only 65 square feet of basal area (15 m^2 per ha), lost only 4 percent of its basal area. Losses in other areas that were cut to densities of less than 65 square feet per acre (14.9 m^2 per ha), but with moderate exposures, averaged about 25 percent.

Other than mortality from the 1962 storm, windthrow mortality has been light in all treatments. Almost invariably, it was associated with damage to root systems by logging machines.

Overstory Growth

Individual trees, and thus stands, do not appear to have responded to increased growing space by increasing total cubic volume growth relative to trees in uncut stands. Dendrometer measurements (see appendix, "The Overstory") were analyzed by covariance, with residual basal area as the independent variable and with initial d.b.h. classes defining treatment groups. There was no significant difference between treatments as to individual tree volume. Evidently, drastic release stimulated basal area growth but decreased height growth by as much as 80 percent.

What this implies is that stand growth in these shelterwood areas has been approximately proportional to the number of residual trees. The predictions of volume growth of the more open shelterwood treatments, based on a local volume table in an earlier report (Williamson 1966), are probably overly optimistic.

LESSER VEGETATION DEVELOPMENT

Crown cover of lesser vegetation averaged 32 percent during the study. This average does not include hemlock crowns, which formed a closed forest overstory approximating 100-percent cover in the beginning of the experiment and which was removed in three stages. Then, as young seedlings, hemlock was again on the way to a closed canopy. Major interest is in relationships between lesser vegetation and hemlock seedlings. Since tree seedlings became established in profusion, an average 32-percent cover of competing vegetation might have affected seedling establishment but obviously did not prevent it.

Canopy coverage of lesser vegetation increased gradually with time (fig. 11) and concurrently with growth of hemlock seedlings (fig. 7). There was a general inverse relationship between overstory and understory density. Treatments with an open forest overstory generally had more dense understory, an expected response to greater sunlight. If anything, the relationship was more variable than expected, apparently due to differences in understory plant cover at the beginning of the experiment. For example, the plot (S-9) that was reduced to 59 square feet of basal area per acre

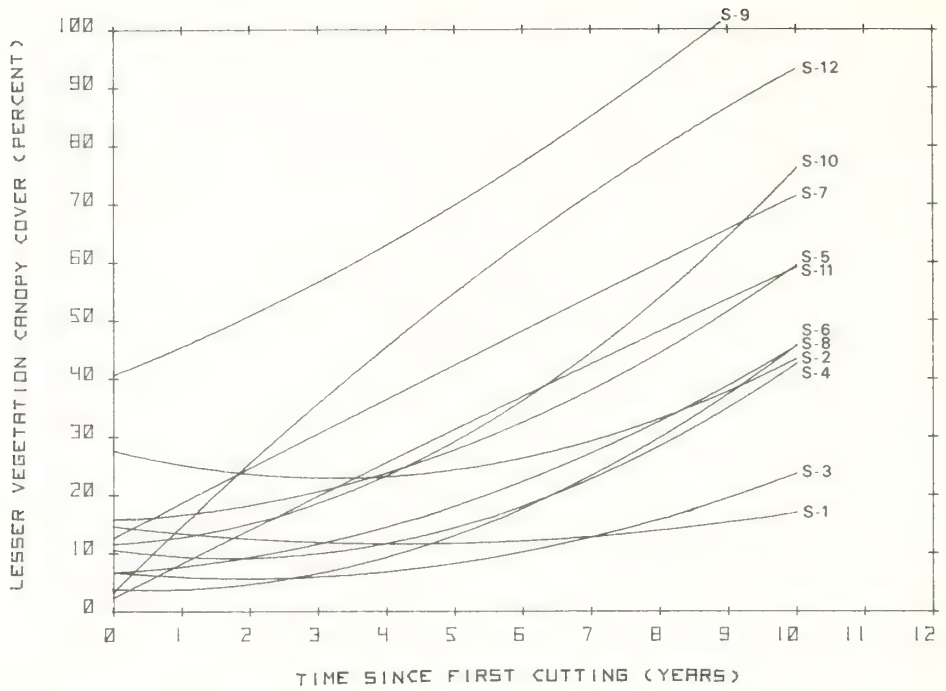

Figure 11.--Relationship of lesser vegetation canopy cover to number of years after first cut, by treatment.

(16 m^2 per ha) by the first cut had 54 percent crown cover of understory vegetation at the beginning of the experiment, more than any other plot. This understory persisted and increased after the shelterwood cuttings. The overall average for this treatment was 74 percent cover compared with the general average of 32 percent. This much competition apparently affected the height growth of hemlock seedlings. The average height of the tallest seedling per milacre was only 3.2 feet (0.98 m), a height similar to treatments that had much more overstory density (fig. 8).

As can be seen in figure 11, lesser vegetation was of no consequence after the second cut, except for two plots (S-9 and S-12) where lesser vegetation was well established before any cutting. Small portions of these two stands had poorly stocked overstories to begin with.

When shrubs and herbs were considered separately, again there was a tendency for treatments with the least basal area per acre in the overstory to have a greater crown cover of shrubs and herbs. There was some tendency for shrub cover to dip down as survivor species faded out, then to increase as invading species became established. Herbs increased rapidly, then leveled off. But this did not occur on all treatments (figs. 12 and 13).

Individual plant species observed on the plots are listed in the appendix. Of these, only five became major components of the ecosystem in terms of canopy coverage. The others generally remained below 10 percent on all treatments.

Salmonberry (*Rubus spectabilis* Pursh), a major competitor elsewhere (Ruth 1970), was present here on all areas and did overtop

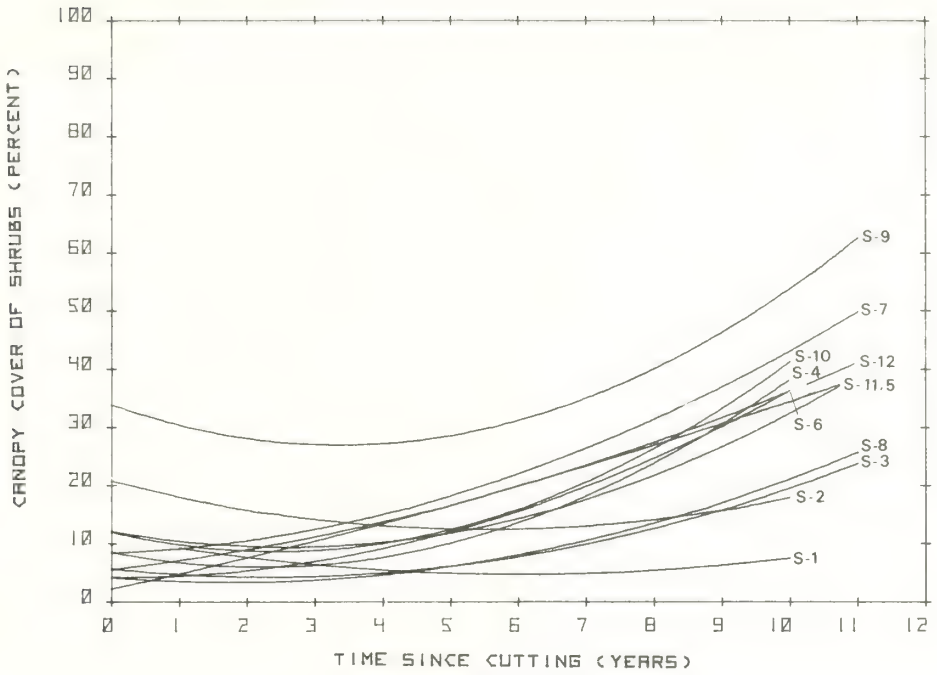

Figure 12.--Influence of time since cutting on canopy cover of shrubs, by treatment.

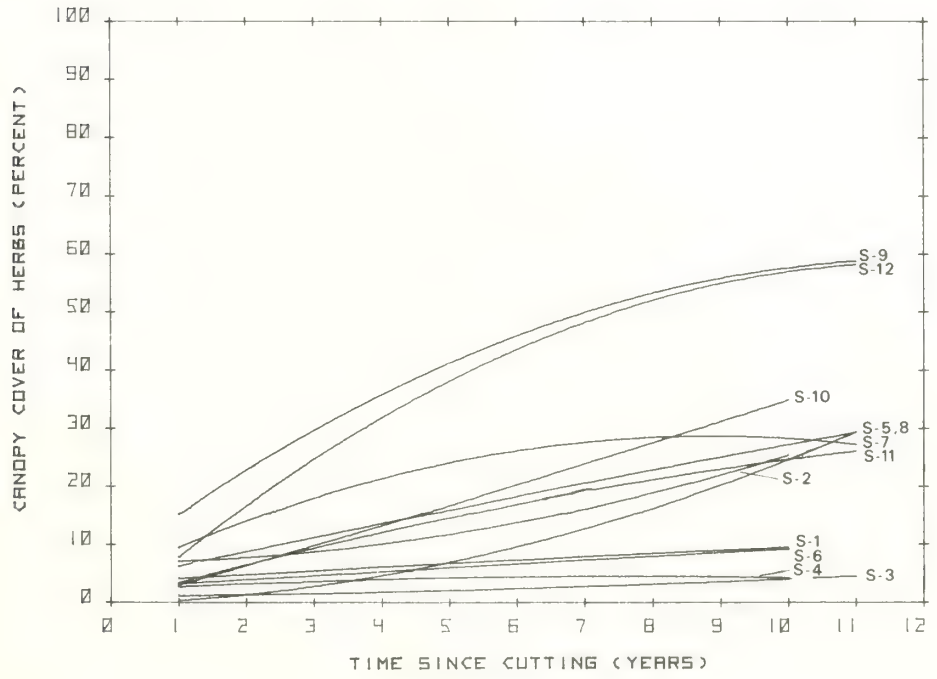

Figure 13.--Influence of time since cutting on canopy cover of herbs, by treatment.

and suppress some hemlock seedlings. Before logging, however, salmonberry was observed on only 3 of the 12 treatment areas; and canopy coverage on these was only 0.1 percent. After logging, salmonberry crowns spread slowly, the plants probably originating from seed rather than sprouts. This gave hemlock seedlings a better chance to compete (fig. 14).

Vine maple (*Acer circinatum* Pursh) was observed on all but one treatment area at the beginning of the study. There were no strong trends to increase or decrease over the study period (fig. 15). Trailing blackberry (*Rubus ursinus* Cham. & Schlecht.) increased only moderately in response to the cutting treatments and, on one treatment area, apparently declined (fig. 16). This was the 59-square-foot basal area per acre (13.5-m^2 per ha) treatment with the most vegetation. Apparently, taller plants overtopped and suppressed the blackberry. Salal (*Gaultheria shallon* Pursh) was heavy on this same treatment area and increased substantially here and on a few other areas (fig. 17). Bracken fern (*Pteridium aquilinum* (L.) Kuhn. var. *pubescens* Underw.) encroached rapidly on only two treatment areas (fig. 18), those which had poorly stocked portions before the first cut.

Red alder, often a severe competitor overtopping hemlock seedlings (Ruth 1965), was only a minor species here. It did appear, mostly on exposed mineral soil along skid roads, but had little overall effect.

In general, competition from lesser vegetation was not serious in the study area. Hemlock seedlings became established between other plants or came up through them. Many were still overtopped at the end of the study. With too many hemlock seedlings, this may be taken as a favorable circumstance.

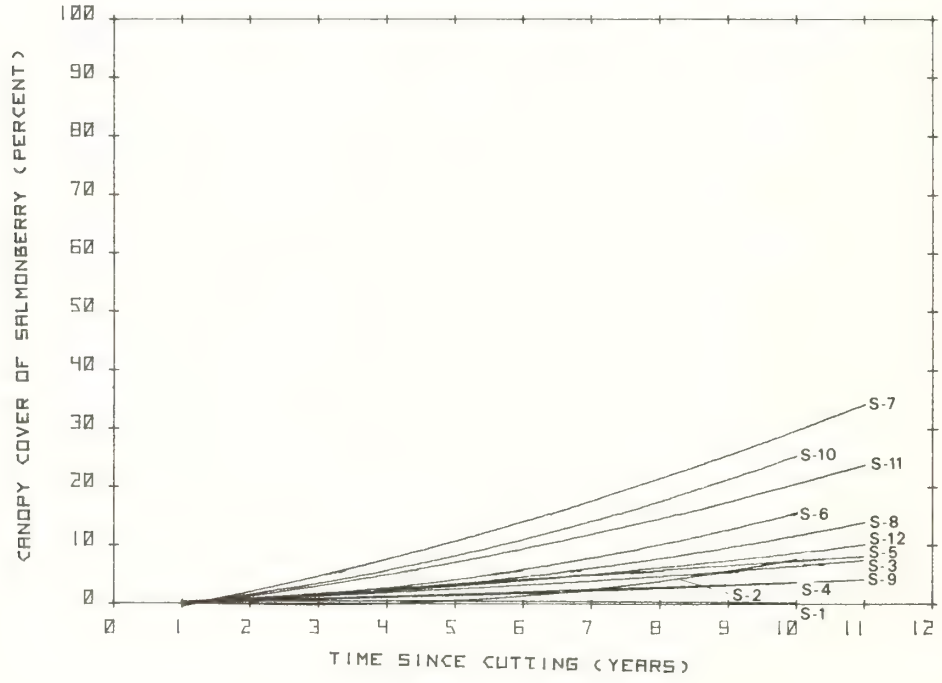

Figure 14.--Influence of time since cutting on canopy cover of salmonberry, by treatment.

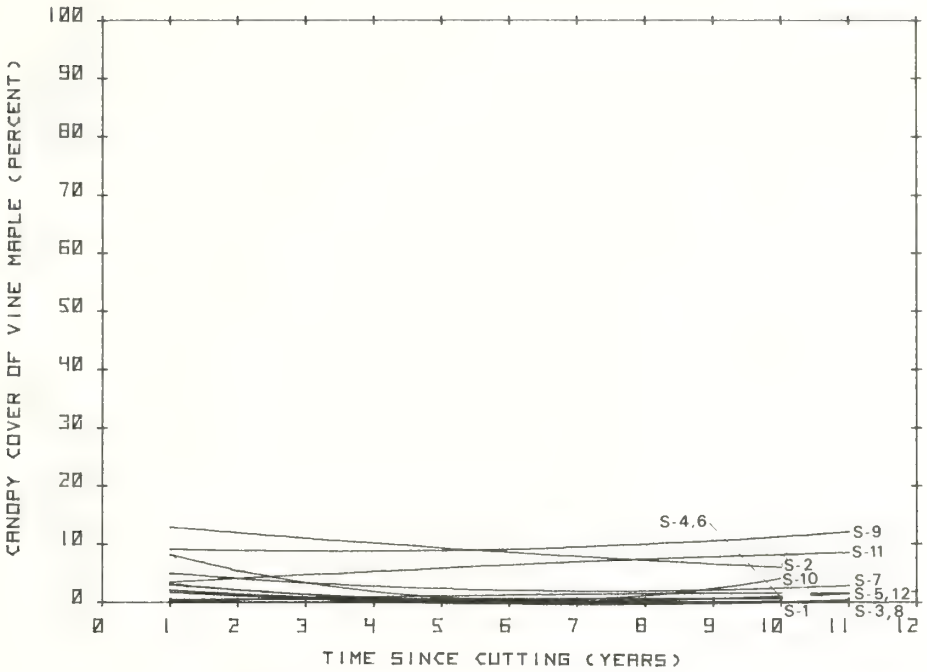

Figure 15.--Influence of time since cutting on canopy cover of vine maple, by treatment.

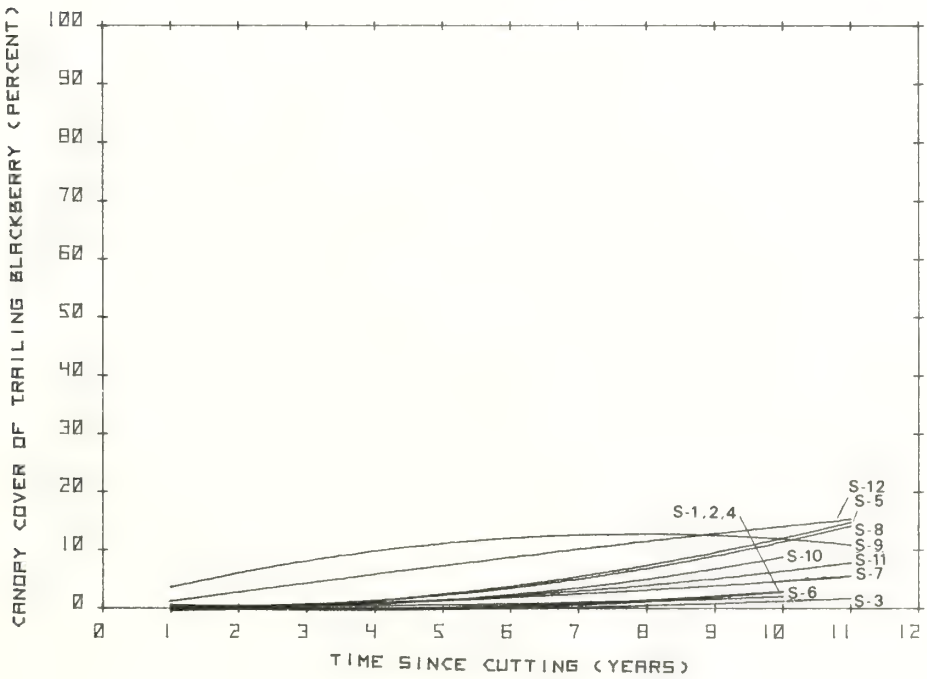

Figure 16.--Influence of time since cutting on canopy cover of trailing blackberry, by treatment.

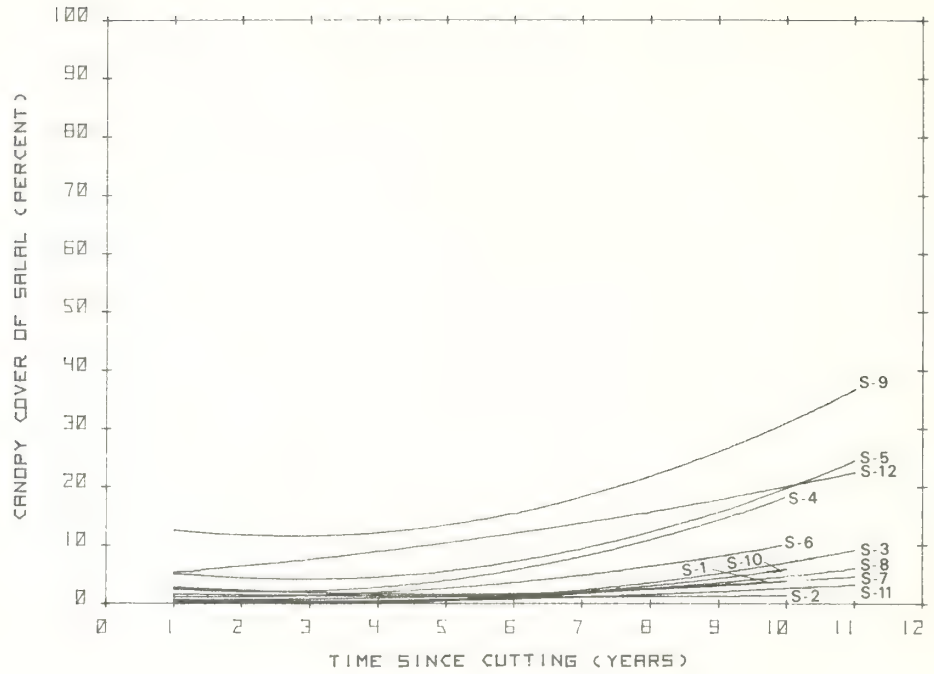

Figure 17.--Influence of time since cutting on canopy cover of salal, by treatment.

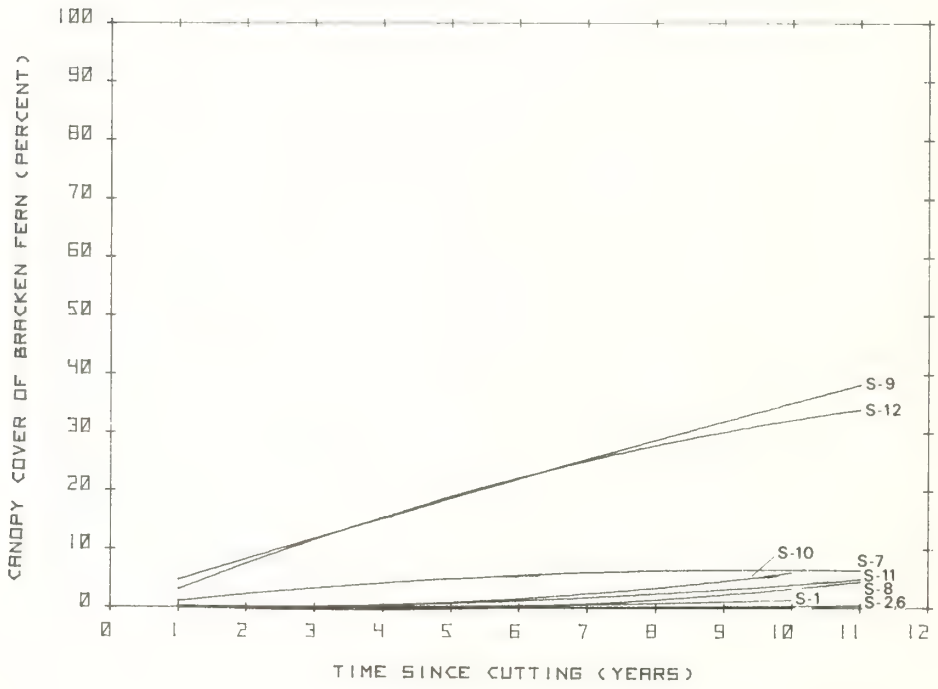

Figure 18.--Influence of time since cutting on canopy cover of bracken fern, by treatment.

Discussion and Conclusions

The silvicultural goal of harvest cutting is to create proper conditions for establishment of a new timber stand. Shelterwood cutting in western hemlock, as applied here, did this--probably too well; there were too many seedlings. There will be intense competition between them beginning at an early age, and cost of precommercial thinning will be high. Treatments leaving the least basal area per acre after the first cut had the fewest seedlings at the end of the experiment, and these seedlings tended to be taller. Yet there was enough for selection of better trees. These light overstories were almost clearcuts, and we might speculate that clearcutting with an adjacent seed source would have provided still fewer and taller seedlings. Logging costs would have been less because it would have been more efficient to remove all the timber at once.

Conversely, after the second cut, we saw that the stands which were densest after the first cut had even fewer seedlings, though still plenty for selection of better trees. The regeneration period, in addition to being two stages instead of three, could be shortened, cutting down further on seedling numbers. This suggests, again, the adequacy of clearcutting. We expect that, under conditions similar to those of the study area, both clearcutting and shelterwood harvesting will generally provide adequate regeneration throughout the coastal hemlock zone in Oregon and Washington. Shelterwood harvesting promises surer regeneration success in brush-threatened areas.

Shelterwood harvesting offers the land manager an opportunity to cut enough trees from a stand to establish regeneration but to hold most of the stand in anticipation of greater returns from a rising market. This study, however, was biologically oriented; and results are limited accordingly. The forest manager must apply the biological data to his particular economic situation.

Shelterwood cutting has been proposed as a means of controlling brush competition and favoring hemlock seedlings. Brush problems were generally not serious in the study area; but even where lesser vegetation was well established before the first cut, more than adequate numbers of hemlock seedlings survived and grew, albeit at a slower rate than that of seedlings in situations where lesser vegetation was initially sparse. We expect that shelterwood secured regeneration in these brush-threatened areas primarily through sheer weight of seed fall, and that brush probably would have captured these areas after they were clearcut. Lesser vegetation was heavier in more open treatments and apparently did affect the numbers of seedlings. But there were too many seedlings anyway and seedlings that came through generally tended to be taller.

Of all the understory species present, none "exploded" or quickly dominated a treatment area. The main problem of competition was on the areas having the most vegetation to start with. We believe that problems from competition can be recognized in advance of cutting and dealt with by appropriate harvesting, residue management, and vegetation control techniques (Ruth 1956, Cramer 1974).

This study area received no site preparation, and such treatment does not seem necessary under these stand and site conditions. There was no problem in securing regeneration without site preparation, and lack of such preparation retains maximum benefits to forest soil (Ruth 1974, Rothacher and Lopushinsky 1974).

Shelterwood cutting has been proposed

as an esthetically viable alternative to clearcutting. Depending on rate of overstory removal, the new stand can be grown to any selected height before removal cut. In this study, heights of the tallest seedlings ranged from about 2 to 8 feet (0.6 to 2.4 m) depending on the density of the overstory (fig. 8). Stumps were well hidden on some treatment areas, not on others; and the appearance varied accordingly. If an overstory is removed promptly after initial seedling establishment, seedlings 3 inches (9 cm) tall for example, the area will look much like a clearcut. However, seedlings will already be established and should grow rapidly to overtop stumps sooner than clearcutting with no seedlings present. If regeneration can be left long enough so that a two-storied stand develops, the overstory may be removed in stages with little more environmental impact than commercial thinnings. Environmentally, the shelterwood system provides wide flexibility. It should find increasing acceptance in areas where the appearance of the forest is particularly important.

The timber stand studied here grew for 60 years before cutting began. That this low level of management is unlikely in the future has important implications. The lighter first cuts resulted in prolific regeneration. The same can be expected after commercial thinning. Surely there will be exceptions; but we think this means, in general, that intensive management through thinning will result in seedling establishment in the understory.

This meets the definition of shelterwood cutting in that seedlings are established under the protection of the overstory. Such areas might be termed accidental or unplanned shelterwood. It appears that whether a harvesting system is called clearcutting or shelterwood cutting may be somewhat arbitrary and may depend on whether or not the establishment and utilization of advance regeneration are part of a planned silvicultural system. Whatever the terminology, the presence of advance regeneration is increasing rapidly with the spread of commercial thinning in hemlock stands. Increasing use of the last commercial thinning to encourage regeneration is a logical development. Once regeneration is established, decisions of the landowner will concern the esthetic question of whether to extend overstory removal to get more height on the regeneration, and techniques of removal that might control spacing of seedlings.

Two research needs regarding the shelterwood system are particularly urgent. Economic analyses are needed to compare the shelterwood system with clearcutting. Second, techniques need to be developed to control and limit seedling establishment. Control of stocking with powersaws or chemicals does this but is costly; and by the time it becomes practical, crop trees already have been held back by intensive competition. Perhaps log yarding techniques for removing the overstory can be developed to destroy seedlings, yet leave a sufficient density of well-distributed seedlings.

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Appendix

DATA COLLECTION AND ANALYSIS

The Overstory

Diameters at breast height of residual trees were recorded after the 1960-61 cut, the 1964-65 cut, and before overstory removal in 1968-69. Diameters of trees cut in 1964-65 were estimated under the assumption that a cut tree grew the same as a residual tree that had the same initial (1960-61) diameter. These diameters were used to calculate growth between the first and second cuts.

A local volume table,[1/] derived from total height and d.b.h. measurements in similar stands throughout the Experimental Forest, was used to estimate volume per acre at each measurement.

Many well-released trees grew remarkably well in basal area during the period between first and second cuts. Thus, the local volume table indicated considerable volume increment. Complete stem measurements, by Barr-Stroud[2/] optical dendrometer, were made in 1967 on a sample of trees, primarily to see if these trees were being buttressed in the lower portions of their stems and thus biasing volume estimates.

Complete stem measurements were recorded for one to four trees (average three) in each of the initial (1960-61) 12-inch (30-cm), 16-inch (41-cm), and 20-inch (51-cm) d.b.h. classes in each of six treatment areas ranging from dense to open and in an uncut stand in an adjacent thinning study. There were 15 measured trees in each d.b.h. class. Our assumption was that trees with similar d.b.h. before treatment (1960-61) then exhibited no more than the usual random variation in cubic volume found in uncut stands. Thus, any statistically significant differences between treatments by 1967, in cubic volume per tree for any diameter class, should reflect treatment effects; and volume growth estimates based on the local volume table could be affirmed or rejected.

Regeneration

Locations of seedlings, both advance and postlogging, 0.3 foot (9 cm) tall or more on the milacre plots were mapped and counted by milacre plot quadrants (one-quarter of a milacre plot) (fig. 19) by the technique described by Neebe and Boyce (1959). Advance regeneration included saplings up to 6-inch (15.2-cm) d.b.h. Initially, sapling-size advance regeneration was distributed throughout the study area. However, most of it was destroyed during logging.

Through the 1964 measurement, postlogging seedling density was generally low enough that all seedlings could be mapped. For 1965 and after, seedling density generally was so great that individual seedlings could not be mapped. Mapping was limited to 10 seedlings per quadrant. We thought consideration of numbers greater than 10 per quadrant was moot because this maximum indicated severe overstocking.

[1/] Volume of trees with both d.b.h. and height measurements were read from table 6 of "Volume tables for permanent sample plots," USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., 1953.

[2/] Use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Figure 19.--Using a sector board to identify seedlings by azimuth and distance from a milacre plot center.

Greater overstocking is not liable to be of practical significance. The height of the tallest seedling per milacre quadrant was recorded at each measurement.

Lesser Vegetation

Canopy density for each species of lesser vegetation on each milacre plot was estimated by methods proposed by Daubenmire (1959). Total coverage was obtained by adding percentages for individual species. In cases of layered vegetation, the total could exceed 100 percent. Nine field estimates of regeneration and lesser vegetation were made during the 12-year study. Common and scientific names of vascular plants found on the study area are listed on page 25.

Illumination

Illumination was measured at the center of each milacre plot, for 1 day in mid-August 1964. The samples were taken at 3 inches above ground to include most lesser vegetation canopy effects as well as those of the overstory. Plot measurements were expressed as percentages of simultaneous measurements made under open sky. Illumination was measured with an anthracene-in-benzene solution, according to principles described by Dore (1958) and procedures described by Rediske et al. (1963).[3/] Percentages obtained were assumed to be reasonable estimates of photosynthetically active light reaching the plots (Vezina and Boulter 1966).

Slash

Depth of slash on each milacre plot was recorded only as being greater or less than 1 foot (0.3 m).

Milacre Plot Characteristics

Aspect was recorded to the nearest octant and percent slope to the nearest degree for each milacre plot.

Analysis

The study was designed for multiple regression analysis, with each unreplicated treatment located randomly within the general study area. Milacre plot values for the above-described independent variables were averaged for each treatment to provide a single observation for each variable per treatment.

3/ The assistance of Dr. M. A. Radwan, Principal Plant Physiologist, Animal Damage Control Project, Pacific Northwest Forest and Range Experiment Station, in the laboratory phases of calibration, standardization, and measurement is gratefully acknowledged.

Because of the bias introduced by the 10-maximum limit on postlogging seedling counts after 1964, no analyses were performed on final numbers of seedlings data. Analyses were performed for the 1965 data. The only independent variable to survive significance tests ($p \leq 0.05$) was overstory basal area.

No statistical tests were made on regressions depicted in figures 7 and 11 through 18 because of lack of independence between successive measurements made on the same plants. The regressions illustrated, however, are unbiased estimators.

LIST OF PLANT SPECIES

Plant species observed on the milacre plots are listed below. Sources for the scientific names are Hitchcock et al. (1955, 1959, 1961, 1964, 1969) for vascular plants except trees, and Little (1953) for trees. Common names are mostly from Peck (1961) and Little (1953).

Scientific name	Common name
Acer circinatum Pursh	vine maple
Alnus rubra Bong.	red alder
Anaphalis margaritacea (L.) B. & H.	pearly everlasting
Athyrium filix-femina (L.) Roth	lady fern
Blechnum spicant (L.) With.	deer fern
Carex spp.	sedge
Dicentra formosa (Andr.) Walp.	western bleeding-heart
Disporum Hookeri var. *oreganum* (Wats.) Q. Jones	Oregon fairy bell
Epilobium angustifolium L.	fireweed
Galium spp.	bedstraw
Gaultheria shallon Pursh	salal
Gramineae	grass family
Hieracium spp.	hawkweed
Hypochaeris radicata L.	hairy cat's-ear
Lysichitum americanum Hult. & St. John	yellow skunkcabbage
Maianthemum dilatatum (Wood) Nels. & Macbr.	false lily-of-the-valley
Menziesia ferruginea Smith	rustyleaf
Mitella pentandra Hook.	fivepoint mitrewort
Montia sibirica (L.) How.	western springbeauty
Oplopanax horridum (J. E. Smith.) Mig.	devil's club
Oxalis oregana Nutt. ex T. & G.	wood sorrel
Picea sitchensis (Bong.) Carr.	Sitka spruce
Polypodium spp.	licorice fern
Polystichum munitum (Kaulf.) Presl	swordfern
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Pteridium aquilinum (L.) Kuhn. var. *pubescens* Underw.	bracken fern
Pyrus fusca Raf.	Oregon crabapple
Rhamnus purshiana DC.	cascara
Ribes spp.	gooseberry or currant
Rubus laciniatus Willd.	evergreen blackberry
Rubus parviflorus Nutt.	thimbleberry
Rubus spectabilis Pursh	salmonberry
Rubus ursinus Cham. & Schlecht.	trailing blackberry
Sambucus cerulea Raf.	blue elderberry
Sambucus racemosa L. var. *arborescens* (T. & G.) Gray	red elderberry
Senecio spp.	ragworts
Stachys mexicana Benth.	great hedge nettle
Tsuga heterophylla (Raf.) Sarg.	western hemlock

Williamson, Richard L., and Robert H. Ruth
1976. Results of shelterwood cutting in western hemlock. USDA For. Serv. Res. Pap. PNW-201, 25 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Twelve shelterwood densities, ranging from 38 to 235 square feet of basal area per acre, were created in a 60-year-old stand. Eleven years after the first cut, regeneration was heavily overstocked under all densities. Brush was adequately controlled by overstory densities of at least 90 square feet of basal area. Overstory volume growth per acre during the regeneration period was approximately proportional to number of trees. Based on clearcutting experience on similar western hemlock sites, shelterwood harvesting probably was not essential for successful regeneration at this location. However, shelterwood cutting is a viable alternative to clearcutting for harvesting and regenerating western hemlock.

KEYWORDS: Shelterwood cutting method, western hemlock, silvicultural systems, natural regeneration.

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1976

ffect of Wildfire on Soil Wettability in the High Cascades of Oregon

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Forest Service, U. S. Department of Agriculture
Portland, Oregon

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EFFECT OF WILDFIRE ON SOIL WETTABILITY IN THE HIGH CASCADES OF OREGON

Reference Abstract

Orness, C. T.
1976. Effect of wildfire on soil wettability in the High Cascades of Oregon. USDA For. Serv. Res. Pap. PNW-202, p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Soil wettability characteristics and revegetation trends were studied for 6 years following the 1967 Airstrip Burn, a 7,700-acre (3116 ha) wildfire which burned in lodgepole pine stands at approximately 5,000-foot (1 524 m) elevation. Wettability of the sand-textured soils was evaluated by liquid-solid contact angle and infiltration rate determinations. Burning apparently increased the water repellency of the soil at depths of 1 to 9 inches (2.5 to 23 cm), which persisted for 5 years after the fire. By the 6th year, contact angle values for both lightly and heavily burned soil were approaching those for the unburned soil. Recovery rates during the 3d and 4th years were more rapid for lightly burned soils than for heavily burned. Two applications of a nonionic wetting agent had almost undetectable effect on soil wettability and rates of revegetation, probably due to rapid downward leaching of the chemical. Yearly vegetation inventories showed a much faster rate of revegetation in lightly burned areas than in heavily burned. Most of the plant species coming in after the fire were present before the burn. Grasses and clover, which were aerially seeded soon after the fire, contributed only negligible amounts of cover.

Keywords: Wildfire (-hydrology, soil condition (-forest damage.

RESEARCH SUMMARY
Research Paper PNW-202
1976

This report summarizes results of the first study undertaken in Oregon on the effects of fire on soil wettability. Although it has long been known that wildfire may cause nonwettable soils elsewhere in the West (and especially in southern California), it is only recently that this same problem has been found in Oregon. During late summer of 1967 a wildfire burned over 7,700 acres (3 116 ha) of predominantly lodgepole pine (*Pinus contorta*) at an elevation of about 5,000 feet (1 524 m) in the Willamette National Forest of Oregon. Following the fire it was noted that certain soil layers showed varying degrees of water repellency. While unburned soils showed moderate resistance to wetting in the surface 2 inches (5.1 cm), burned soils were wettable in the surface but were strongly nonwettable at 2 to 6 inches (5.1 to 15.2 cm). This

water repellency was causing increased runoff and erosion. Preliminary analysis indicated these burned soils had a higher degree of water repellency than most nonwettable soils in southern California (DeBano 1969).

In order to explore these relationships more fully, soil wettability characteristics and revegetation trends were studied for 6 years following the 1967 Airstrip Burn. Wettability of the sand-textured soils was evaluated by liquid-soil contact angle and infiltration rate determinations. Results indicated that fire caused increased water repellency in burned soils. Although burned soils were slightly more wettable than unburned soils in the surface inch, substantial increases in water repellency were found for the 1- to 6-inch (2.5- to 15.2-cm) soil depths in burned areas. Decreases in soil wettability persisted in the burned areas for 5 years after the fire. By the 6th year, contact angle values for the burned soil samples were approaching those measured in the unburned soil. Recovery rates during the 3d and 4th years were more rapid for lightly burned soils than for heavily burned.

Vegetation inventories showed a much faster rate of revegetation on lightly burned plots than on the heavily burned. Most species coming into the burned areas were also present before the fire. Grasses and clover which were aerially seeded soon after the burn contributed only negligible amounts of cover.

In 1968 and 1969, the wetting agent Aqua-Gro was applied to half the plots in each condition (unburned, lightly burned, and heavily burned). No effect on plant growth could be determined. Effects of the wetting agent on soil wettability were minimal. Apparently nonionic surfactants offer little promise as a practical method for ameliorating the detrimental soil effects of burning, at least in areas receiving sufficient precipitation to leach them from the soil profile.

Wildfires in areas of sandy soils on steep slopes could lead to serious erosion problems caused, in large part, by decreased soil wettability. Since decreased soil wettability persists for several years, it is essential that the land manager act immediately to aid soil stabilization as soon as the fire is controlled. Probably the most effective treatment would be immediate seeding of well-adapted grass and legume species and the liberal application of a nitrogen fertilizer.

INTRODUCTION

Nonwettable soils have been studied ost intensively in the San Gabriel Mountins of southern California. Following a 962 fire adjacent to the San Dimas Experiental Forest, the surface soil over much the burned area was found to exhibit arked nonwettable properties (Osborn al. 1964, Krammes and DeBano 1965). fter rainstorms, it was noted that hough the surface inch or two of soil as saturated, the layer immediately low was generally comprised of air-dry il. Subsequent research has indicated t due to decreased infiltration rates, il erosion during rainstorms is considably greater in areas of nonwettable ils (Osborn et al. 1964, DeBano et al. 67).

The agent responsible for the formain of nonwettable soils in southern Calinia appears to be organic substances oduced by shrub species. Letey et al. 962) demonstrated that extracts of haparral litter can produce nonwettability npreviously wettable sands. DeBano 966) suggested that the formation of a nwettable soil layer may be the result a hydrophobic organic compound volaizing due to the heat of the fire and later ndensing on cooler soil particles. More ent work by Savage et al. (1972) demontated that water repellency of burned ls was the result of heating of surface ter. The effective water-repellent subnces were collected and identified as bhatic hydrocarbonlike materials.

The application of wetting agents pears to offer some promise for meliorating the effects of soil nonwettaity. Early plot experiments in southern lifornia demonstrated reduced erosion n improved establishment of vegetation s a result of the application of wetting nts (Osborn et al. 1964, Krammes and sborn 1969). However, aerial application of a wetting agent to an entire burned-over watershed near Glendora, California, had no effect in decreasing soil erosion (Rice and Osborn 1970). Thus, the usefulness of large-scale applications of wetting agents to forest soils on an operational basis is not yet demonstrated.

Recently it has become increasingly apparent that resistance to soil wetting is a widespread phenomenon in the Western United States, especially following fire. DeBano (1969a) reported that, in addition to California, water-repellent soils have been observed in Oregon, Idaho, Montana, Nevada, Utah, Colorado, Arizona, and New Mexico. The study reported here was conducted in an area where water repellency was more severe than has been reported for any other area within the Western United States (DeBano 1969a, 1969b).

During late August and early September of 1967, a wildfire swept through 7,700 acres (3 116 ha) of predominantly lodgepole pine (*Pinus contorta* Dougl.) forest land in the Willamette National Forest of Oregon. During the first fall rains after the fire, it was noted that considerable runoff and erosion were occurring due to decreased infiltration rates. Further investigation disclosed that certain soil layers were exhibiting varying degrees of water repellency. In lightly burned areas, the soil at a depth of 1 to 3 inches (2.5 to 7.6 cm) showed strong nonwettable properties, while at 3 to 6 inches (7.6 to 15.2 cm) the soil was moderately resistant to wetting. Severely burned soils tended to be wettable from 0 to 3 inches (0 to 7.6 cm) and nonwettable at 3 to 6 inches (7.6 to 15.2 cm). At the same time, unburned soils exhibited moderate resistance to wetting in the surface 2 inches (5.1 cm), with wettable soil beneath.

In order to investigate the effects of burning on soil wettability in more detail, an exploratory study was begun during the

summer following the fire (1968). The study had two main objectives: (1) to determine the effects of burning on soil wettability and to discover how long such effects persist, and (2) to determine the effect of the application of a wetting agent on soil wettability and revegetation.

STUDY AREA

The study was conducted in the 7,700-acre (3 116 ha) Airstrip Burn on the crest of the Cascade Range near Santiam Pass, Willamette National Forest. The fire occurred during the period of August 28 until September 8, 1967. The pattern of burning included several areas of very severe burn, some light burn with only partially killed tree crowns, and some completely unburned islands.

Vegetation before the fire consisted of a rather open pole-size stand predominantly of lodgepole pine with varying amounts of subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga mertensiana*).[1/] Understory vegetation was fairly scattered, with perhaps a maximum of 40- to 45-percent total cover. The most abundant species were sickle-keeled lupine (*Lupinus albicaulis*) and long-stoloned sedge (*Carex pensylvanica*). Species contributing smaller amounts of cover included the grasses western stipa (*Stipa occidentalis*) and bottle-brush squirrel-tail (*Sitanion hystrix*), and squaw currant (*Ribes cereum*) and Bloomer's haplopappus (*Haplopappus bloomeri*).

The study area is situated within the High Cascades geologic province. Bedrock in the area is made up of basalts and andesites laid down during the Pleistocene. The bedrock is overlain by deep, relatively recent deposits of vocanic ash, cinders, and pumice. The principal soil in the area is a poorly developed Vitrandept, exhibiting 2-inch (5.1 cm) A1 and 10- to 12-inch (25.4- to 30.5-cm) AC horizons. Soil textures are coarse--ranging from a loamy sand to a sandy loam. Slopes are gentle within the burn, except for several isolated buttes and volcanic cones. Elevations range from about 4,640 to 5,460 feet (1 414 to 1 664 m) above sea level. The area is characterized by dry summers and an annual precipitation of about 95 inches (2 413 mm), much of which is snow.

Following the fire (October 1967), the area was aerially seeded with grass, clover, and tree seed. Species seeded included tall fescue (*Festuca arundinacea*), perennial ryegrass (*Lolium perenne*), white clover (*Trifolium repens*), lodgepole pine, ponderosa pine (*Pinus ponderosa*), and western white pine (*Pinus monticola*).

STUDY METHODS

Vegetative cover was estimated in early September of each year (1968 through 1973) on milacre plots. These plots were square (6.6 feet (2 m) on a side), with one-quarter of the large plot subdivided into nine subplots, each 1.1 foot (0.34 m) square. Cover of shrub and tree species was estimated on the large plot and herbaceous cover, on the nine subplots. Ten sets of paired plots were located at 50-foot (15.2-m) intervals along transects in each of three areas--heavily burned, lightly burned, and unburned. Thus there were 20 plots in each condition for a grand total of 60 plots. One plot of each pair remained untreated, while the other plot was treated with a wetting agent.

Of 10 plot pairs in each condition, 2 pairs (4 plots) were randomly selected as soil sample plots. Here soil wettability samples were collected and infiltration tests made each time the vegetation was inventoried (early September of each year).

[1/] Plant names are from Franklin and Dyrness (1973).

Soil samples were collected from the following depths:

0- to 1-inch (0- to 2.5-cm)
1- to 2-inch (2.5- to 5.1-cm)
2- to 4-inch (5.1- to 10.2-cm)
4- to 6-inch (10.2- to 15.2-cm)
6- to 9-inch (15.2- to 22.9-cm)
9- to 12-inch (22.9- to 30.5-cm).

In 1968, one set of samples was collected from each sample plot. However, in 1969 through 1973, two sets of soil wettability samples were collected at each soil sample plot, for a total of 144 per year. Infiltration capacity was estimated each year using ring infiltrometers 6 inches (15.2 cm) in diameter. The time necessary for the infiltration of 3 inches (76.2 mm) of water was determined at three locations per plot.

In August of 1968 and June of 1969, one plot of each pair was treated with the wetting agent Aqua-Gro,[2/] a nonionic surfactant. In 1968, the wetting agent was applied at the manufacturer's recommended rate, which totaled 35 milliliters of Aqua-Gro per plot. The rate was doubled to 70 milliliters per plot in 1969. For each treated plot the Aqua-Gro was mixed with 7.5 liters (2 gallons) of water and applied by sprinkling it onto the plot surface.

Soil samples were air dried soon after they were brought into the laboratory. Samples were then placed in petri dishes and relative wettability determined by the water drop test. Several drops of water were placed on each soil sample, and the length of time necessary for the water to soak into the soil was measured.

Liquid-solid contact angles were also determined for all samples, using the method suggested by Letey et al. (1962). This is a capillary rise technique which involves measuring height of rise in soil columns placed in water and in ethanol. Air-dried soil was packed to an equal density in two glass tubes 8-9 millimeters in diameter. These were held vertical for 24 hours, with the lower end of one column immersed in water and the other in ethanol. The heights of the wetting fronts were then measured. The liquid-solid contact angle was calculated from:

$$\text{Cos angle} = 0.3961 \frac{\text{height water}}{\text{height ethanol}}.$$

Results of contact angle determinations were analyzed by a single analysis of variance. In this analysis, the 1968 data were omitted because the wetting agent treatment was not complete until 1969. This approach to statistical analysis is relatively complex because of the four variables involved--burning treatment wetting agent treatment, soil depth, and year. However, the single analysis alternative was adopted as offering the most effective means of exploring possible interactions among variables.

RESULTS

SOIL WETTABILITY

Drop tests as a means of assessing soil wettability gave somewhat unsatisfactory results. We found it extremely difficult to obtain reproducible time readings, probably due to combined effects of variation within a soil sample and the difficulty of subjectively determining when a water drop had actually soaked into the soil. It became especially difficult after 2 hours to distinguish between absorption and evaporation. Consequently, all readings of 2 hours and longer were arbitrarily assigned to a "water drop evaporated" category.

[2/] Supplied in liquid form by Aquatrols Corporation of America, Camden, N.J. Trade names and commercial products or enterprises are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

Correlation between water drop results and liquid-solid contact angle determinations were generally poor. The erratic nature of drop test results is shown in figure 1. Despite some initial difficulties in obtaining consistent, reproducible contact angle data (largely due to a lack of uniformity in soil density in the glass tubes), contact angle results appear much more reliable and consistent than do drop test results. Consequently, discussion of changes in soil wettability will be based exclusively on liquid-solid contact angle data. Resistance to wetting is directly proportional to the magnitude of the liquid-solid contact angle. Thus, contact angles greater than 80 degrees indicate extreme resistance to wetting, and those in the 70-degree range represent at least moderate resistance to wetting.

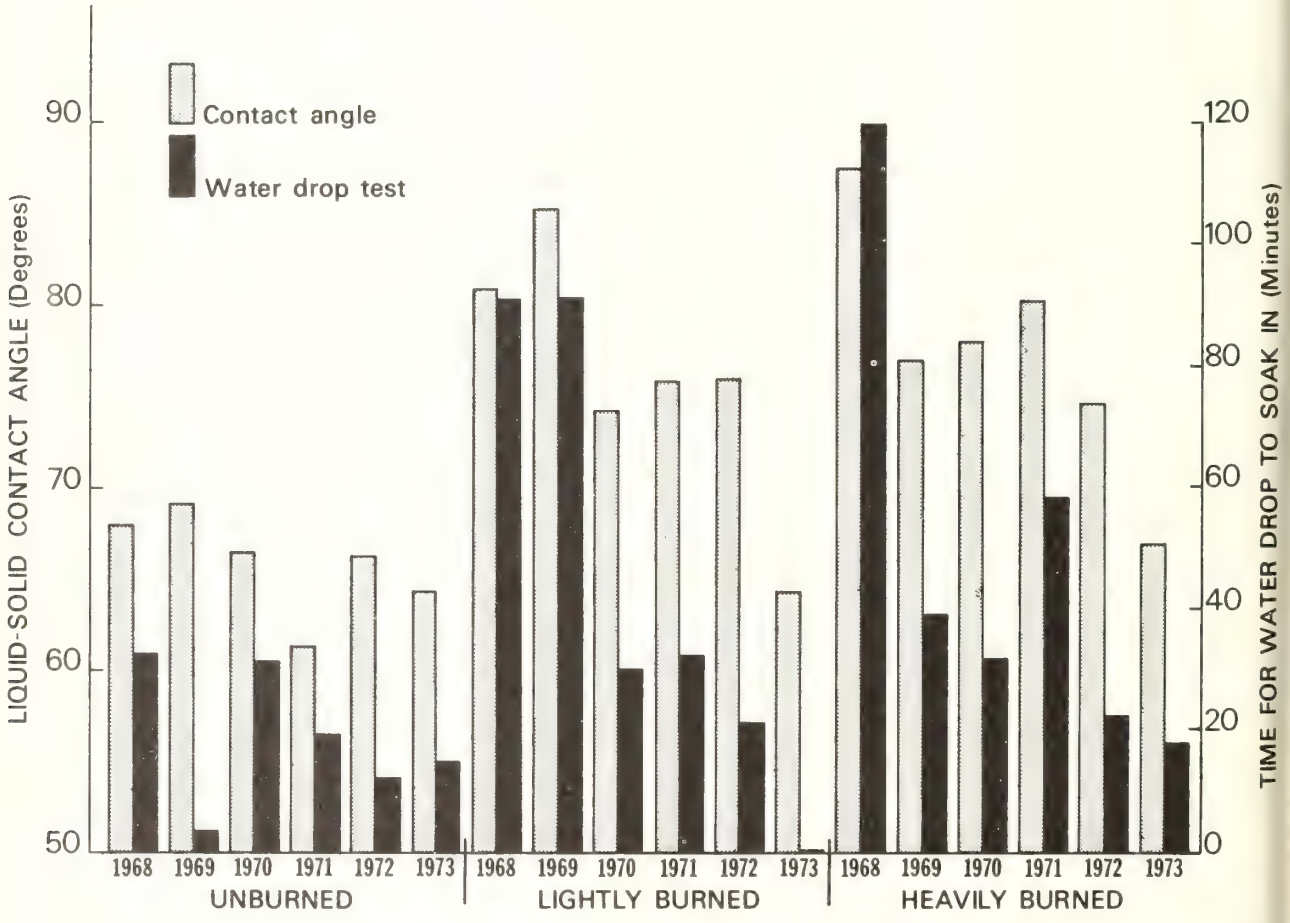

Figure 1.--Liquid-solid contact angles and water drop test results for the 1- to 2-inch (2.5- to 5.1-cm) soil depth in heavily burned, lightly burned, and unburned areas for 6 years after burning. Each value represents the mean of eight measurements, except for 1968 where each value represents four measurements.

Results of analysis of variance for the liquid-solid contact angle data are presented in table 1. Despite the fact that effect of burning is nonsignificant, burning has apparently caused some decrease in soil wettability, especially at the 1- to 6-inch (2.5- to 15.2-cm) depths (fig. 2). This is also shown in table 2, where the overall, 5-year contact angle means are 65.61, 71.09, and 75.02 degrees, respectively, for unburned, lightly burned, and heavily burned areas. The lack of statistical significance for an overall burning treatment effect was probably caused by the combined masking effects of the other three variables--wetting agent treatment, soil depth, and years.

Although the effect of soil depth alone is nonsignificant, there is a highly significant soil depth X burning treatment interaction (table 1). The nature of this interaction is illustrated in table 2. Apart from an appreciably higher value in the 0- to 1-inch (0- to 2.5-cm) soil layer, contact angle values remain approximately constant at all depths for the unburned soil. However, in the burned soils, and especially the heavily burned, there is considerable variation in contact angle with soil depth. Here the general pattern is a lower contact angle in the surface inch, an abrupt increase in the 1- to 4-inch (2.5- to 10.2-cm) layers, followed by a gradual decrease in angles with depth. These relationships are shown in figure 2.

Table 1--*Analysis of variance for liquid-solid contact angles for samples collected for 5 years (1969-73) after a wildfire*

Source of variation	Symbols	d.f.	SS	MS	F
Total		359	27,307		
Burning treatment (unburned, lightly burned, heavily burned)	E	2	5,351	2,676	2.41
Error (a)	A + AE	3	3,327	1,109	
Wetting agent treatment (treated, untreated)	B	1	22	22	.05
Wet X burn	BE	2	133	66	.16
Error (b)	AB + ABE	3	1,225	408	
Soil depth sampled (0-1, 1-2, 2-4, 4-6, 6-9, and 9-12 inches)	C	5	402	80	1.33
Depth X burn	CE	10	3,100	310	5.08**
Depth X wet	BC	5	604	121	1.98
Triple interaction	BCE	10	244	24	
Error (c)	AC + ACE + ABC + ABCE	30	1,819	61	
Years (1969, 1970, 1971, 1972, 1973)	D	4	2,944	736	32.00**
Years X burn	DE	8	1,342	168	7.30**
Years X wet	BD	4	325	81	3.52**
Triple interaction	BCD + BDE + CDE	68	1,464	22	
Quad interaction	BCDE	40	853	21	
Error (d)	AD + ABD + ACD + ADE + ABCD + ABDE + ACDE + ABCDE	144	3,350	23	

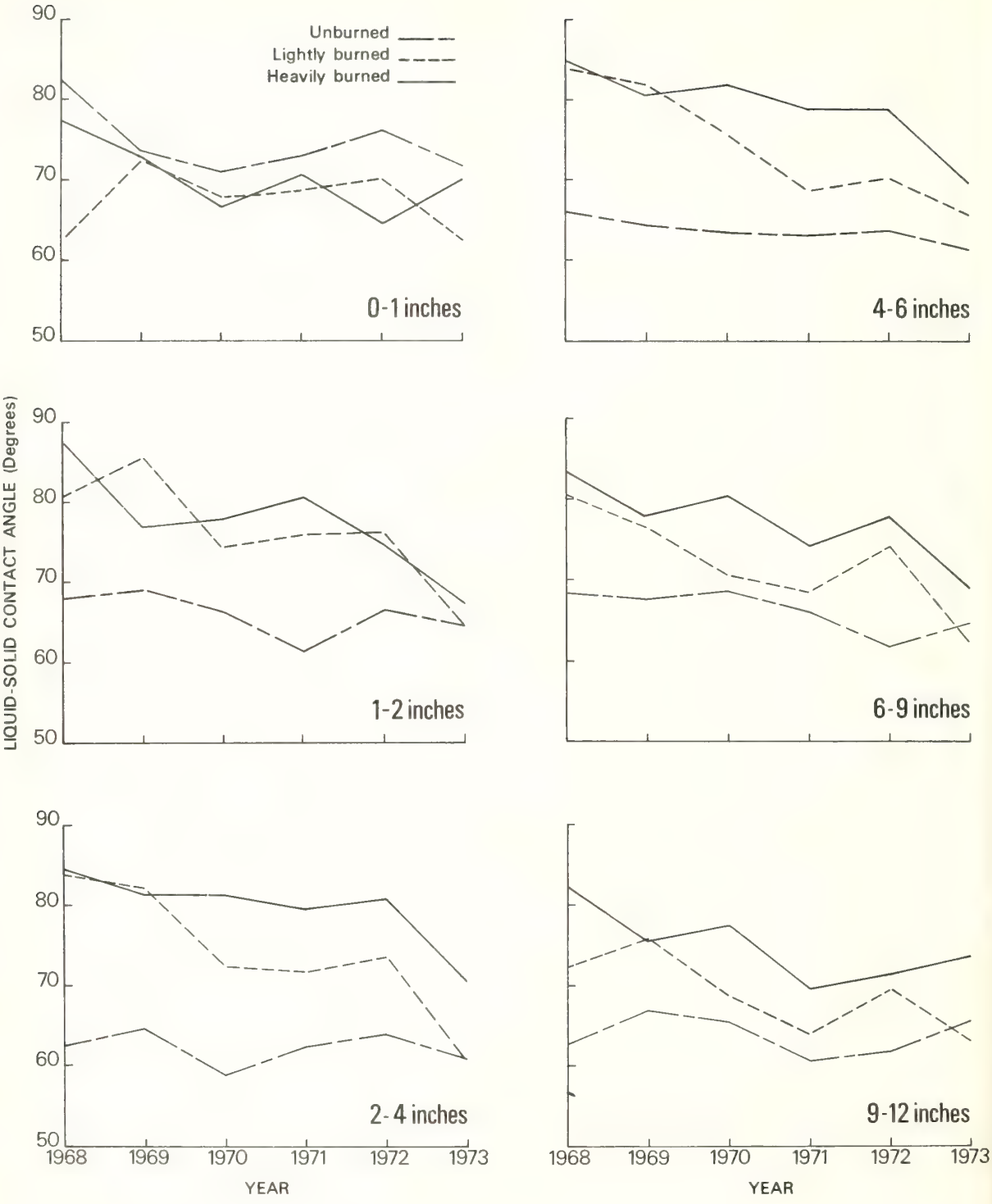

Figure 2.--Mean liquid-solid contact angle values for samples collected at six soil depth intervals in heavily burned, lightly burned, and unburned areas during the first 6 years after the fire. Each value represents the mean of eight measurements, except for 1968 where each value represents four measurements.

Table 2--*Means of liquid-solid contact angles by soil depth and burning treatment. Data for all years (1969-73) and wetting agent treatments (treated and untreated) are pooled*

Soil condition	Soil depth (inches)						
	0-1	1-2	2-4	4-6	6-9	9-12	Mean
	Degrees						
Unburned	73.16	65.38	62.14	63.23	65.76	64.01	65.61
Lightly burned	68.31	75.22	72.12	72.28	70.34	68.24	71.09
Heavily burned	68.87	75.46	78.62	77.86	75.77	73.52	75.02
Mean	70.11	72.02	70.96	71.12	70.62	68.59	70.57

Relationships among soil depth, burning effects, and soil wettability may be summarized as follows: In the surface inch of soil, resistance to wetting was apparently slightly greater in the unburned control than in areas subjected to burning (table 2, fig. 2). At the 1- to 2-inch (2.5- to 5.1-cm) depth the relationship was reversed, with the burned soils definitely showing a greater resistance to wetting than the unburned. This general relationship also held for the 2- to 4- and 4- to 6-inch (5.1- to 10.2-cm and 10.2- to 15.2-cm) depth intervals where the burned soils were clearly more resistant to wetting (table 2, fig. 2). At 6 to 9 and 9 to 12 inches (15.2 to 22.9 and 22.9 to 30.5 cm), differences among burning treatments were smaller; although here, too, the burned soils appear to be more resistant to wetting than the unburned. In every case, the relationship between lightly burned and heavily burned soils was as would be expected; i.e., the heavily burned soil showed more resistance to wetting than the lightly burned (table 2, fig. 2).

How long do these effects on soil wettability persist? This question is at least partially answered by a consideration of analysis of variance results (table 1). These results indicate a highly significant year effect. Although there is very little year-to-year change in liquid-solid contact angles of the unburned soil, values for the burned soil show a general downward trend and a very marked decrease in 1973 (table 3). The absence of year-to-year change in unburned soil probably explains the significant year X burning treatment interaction shown in table 1.

Both the mean contact angle curves in figure 2 and the data presented in table 3 indicate that by the 6th year after burning (1973), differences among treatments had become relatively small. As might be expected, there is some indication that decreased soil wettability may be more persistent in heavily burned soils than in soils subjected to more moderate burning (fig. 2). Note especially trends for the 2- to 4- and 4- to 6-inch (5.1- to 10.2- and 10.2- to 15.2-cm) depths. Here mean contact angle values for the heavily and lightly burned classes were almost identical for the first 2 years after burning (1968 and 1969). However, during the next 2 years, values for the lightly burned treatment

Table 3--*Means of liquid-solid contact angles by year and burning treatment. Data for all six soil depth intervals and wetting agent treatments (treated and untreated) are pooled*

Soil condition	1969	1970	1971	1972	1973	Means
	- - - - - - - - - - - - - - - - *Degrees* - - - - - - - - - - - - - - - -					
Unburned	67.62	65.61	64.38	65.68	64.77	65.61
Lightly burned	79.04	71.58	69.58	72.25	62.98	71.09
Heavily burned	77.46	77.55	75.54	74.65	69.86	75.02
Mean	74.71	71.58	69.83	70.86	65.87	70.57

decreased markedly while contact angles for heavily burned soils decreased only slightly. In these layers, there was not a marked decrease in contact angles for samples from the heavily burned area until 1973 when, in both cases, mean values dropped almost 10 degrees.

Application of the wetting agent, Aqua-Gro, on half the plots in August of 1968 and again in 1969 had little discernible effect on soil wettability as evaluated by liquid-solid contact angle measurements. Neither the wetting agent treatment effect nor the wetting agent X burning treatment interaction was statistically significant (tables 1 and 4). The only significant relationship involving the wetting agent treatment was the wetting agent X year interaction (table 1). An examination of the means (table 5) shows that although mean angles were slightly higher for untreated soils in 1969 and 1970, this difference had disappeared by 1971. Thus, there is some indication that there may be a slight positive effect as a result of wetting agent application which persists for only a brief time. As a result, apparent wetting agent effects are most noticeable in results for samples collected in 1969, approximately 1-1/2 months after the heaviest application of Aqua-Gro. As shown in figure 3, the wetting agent apparently had the greatest effect on the unburned soils and had relatively little effect on burned plots except in the 1- to 2-inch (2.5- to 5.1-cm) heavily burned layer.

INFILTRATION

Measured infiltration rates indicated that soils in unburned areas absorbed water at a rate which was roughly three times faster than soils in burned areas (fig. 4). For example, 1 year after the fire (1968) the average infiltration rate for unburned soils was about 37 inches (940 mm) per hour compared with 14 and 7 inches (356 and 178 mm) per hour for heavily and lightly burned soils, respectively. Despite apparent increases in soil wettability, especially in 1972 and 1973, recovery in infiltration rates was not pronounced (fig. 4). However, there was a gradual increase in infiltration rate on lightly burned plots over the 6-year period--from 7 inches (178 mm) per hour the 1st year after burning to over 13 inches (330 mm) per hour 6 years after burning. Infiltration rates in heavily burned areas were more erratic, with highest rates measured the 1st year after burning.

Table 4--*Means of liquid-solid contact angles by burning treatment and wetting agent treatment. Data for all years (1969-73) and at all six soil depths are pooled*

Soil condition	Treated with wetting agent	Untreated	Mean
	Degrees		
Unburned	69.30	61.92	65.61
Lightly burned	67.76	74.41	71.09
Heavily burned	76.76	73.27	75.02
Mean	70.32	70.82	70.57

Table 5--*Means of liquid-solid contact angles by year and wetting agent treatment. Data for all six soil depths and three burning treatments (unburned, lightly burned, and heavily burned) are pooled*

Treatment	1969	1970	1971	1972	1973	Mean
	Degrees					
Untreated	76.19	72.51	69.92	69.53	65.95	70.82
Treated with wetting agent	73.23	70.65	69.75	72.19	65.79	70.32
Mean	74.71	71.58	69.83	70.86	65.87	70.57

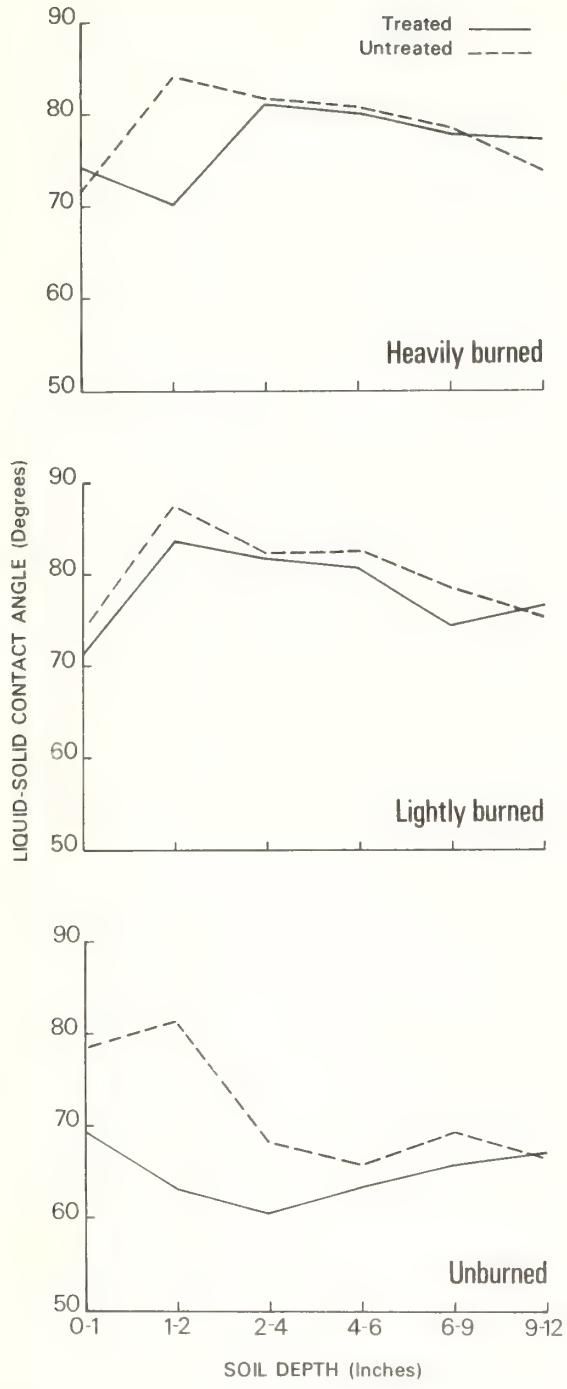

Figure 3.--Mean liquid-solid contact angles for soil samples collected in September 1969 at six depth intervals in lightly burned, heavily burned, and unburned areas. Half the plots were treated with a wetting agent in June 1969. Each value represents the mean of four measurements.

Application of the wetting agent may have had some effect in increasing infiltration rates during the first 3 years after burning. Rates for treated soils were approximately 24 percent higher than those for untreated soils during this period (fig. However, variation among individual measurements was high, making it impossible to state that these differences, from a statistical viewpoint, are real rather than coincidental. During the final 3 years of measurement, wetting agent application apparently had little residual effect--mean untreated infiltration rates were higher than treated rates in five of nine comparisons (fig. 4).

Wetting patterns in the dry soil following early fall rains indicate why infiltration rates were low in burned areas and also explain the substantial variation among measurements. In September of 1969, the first fall rains after the summer dry period produced a highly variable pattern of soil wetting (figure 5). In general, the rain, which had totaled approximately 1.4 inches (36 mm) at the time of observation, had saturated only 1 or 2 inches of the surface soil. This saturated zone was most often underlain by a layer of dry soil ranging from 3 to 9 inches (7.6 to 22.9 cm) thick which was, in turn, situated on top of wet soil. It was obvious that the lower boundary of the dry soil layer constituted a wetting front which was gradually moving upward by capillarity. Closer inspection revealed scattered points at which the lower wet zone was supplied water via old root channels or soil which for some reason was not as water repellent. Once this downward percolating water reached the lower, less water-repellent portions of the profile, it would then spread out and begin its slow capillary ascent into those layers (about 2 to 9 inches (5.1 to 22.9 cm in depth) with more pronounced hydrophobic properties.

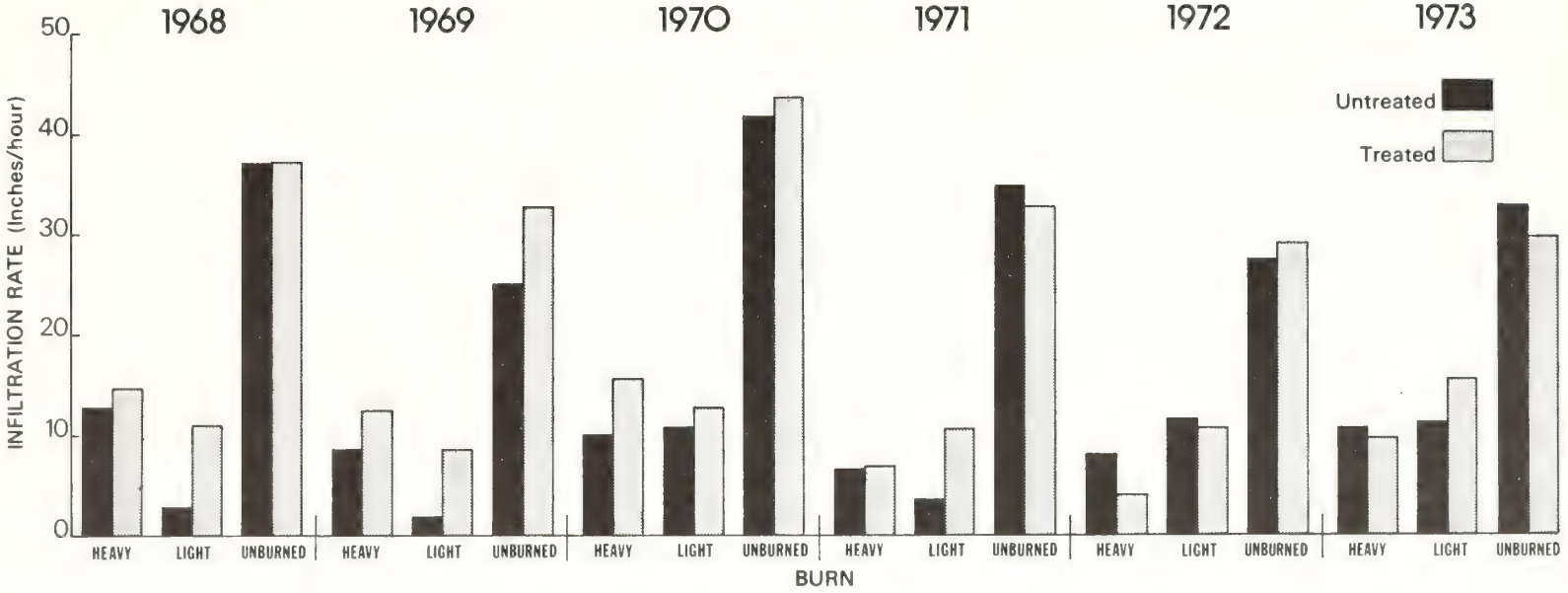

Figure 4.--Mean infiltration rates for untreated plots and plots treated with a wetting agent in heavily burned, lightly burned, and unburned areas for the first 6 years after the fire. Each value represents the mean of the results of six infiltrometer runs.

Figure 5.--Soil wetting patterns in a heavily burned area 2 years after the fire. Photo was taken after 1.4 inches of rain had fallen following a long dry period. Dark soil areas are wet; the light patches are dry.

VEGETATION TRENDS

Before burning, the study site was characterized by relatively sparse vegetation and an extremely depauperate flora. The vegetation plots located in the unburned island contained only 15 vascular plant species. Tree canopy coverage on these plots totaled slightly over 40 percent, and scattered understory plants contributed only about 30-percent coverage (table 6). Revegetation trends on burned plots for 6 years following the fire show a much faster rate of recovery for lightly burned plots compared with those in a heavily burned area. At the end of the 6-year period, lightly burned plots had almost twice as much plant cover as the heavily burned plots (table 6). By 1973, total plant coverage in the lightly burned area was approaching that found in the unburned control.

Table 6 shows that application of the wetting agent in August of 1968 and again in 1969 had no consistent effect on the vegetation. This is contrary to experience elsewhere, in which application of wetting agents to nonwettable soils has resulted in a spectacular increase in plant growth. For example, in a study following a wildfire in the San Dimas Experimental Forest (southern California), plots treated with a wetting agent had four times more grass cover than untreated plots (Osborn et al. 1964). Apparently, in the present study, the nonionic surfactant was leached out of the rooting zone before it could affect plant growth. Most germination and growth occurs early in the summer before the time of the wetting agent application. Since this is an area of summer drought and concentrated winter precipitation, this leaching process would probably be completed before the start of the next growing season. Annual precipitation during the study period averaged about 95 inches (2 413 mm), undoubtedly more than enough to completely leach the surfactant from the upper soil profile.

e 6--Estimated coverage of common plant species on untreated plots and plots treated with a wetting agent for the first 6 years following the fire. Wetting agent was applied in midsummer in 1968 and 1969, all cover estimates were made in September

Soil condition and species	1968		1969		1970		1971		1972		1973	
	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated
						Percent						
nburned plots												
d grasses												
upinus albicaulis	18.8	18.6	21.4	27.3	17.5	24.0	19.3	24.8	19.9	25.0	18.9	21.8
arex pensylvanica	3.0	4.0	2.5	4.7	2.6	4.3	2.4	2.9	2.4	3.5	2.9	3.4
tipa occidentalis	2.6	3.8	4.4	5.6	2.7	4.1	2.6	5.2	3.2	4.9	3.4	4.0
enstemon procerus	2.7	.3	2.5	.2	2.4	.2	2.5	.1	2.5	.1	2.9	.1
ther species	.1	1.6	0	1.3	.1	.8	.3	.7	.1	.8	0	1.1
otal herb layer cover	25.9	26.2	28.0	34.9	23.2	30.5	25.0	33.1	26.5	32.2	23.1	30.0
s												
ibes cereum	0	6.0	0	5.0	0	5.0	0	6.0	0	4.5	0	5.0
otal shrub layer cover	0	6.0	0	5.0	0	5.0	0	6.0	0	4.5	0	5.0
inus contorta	32.1	40.6	30.6	44.6	32.6	44.0	30.1	41.5	32.1	37.1	30.6	36.3
bies lasiocarpa	10.9	11.8	11.1	12.3	10.7	12.7	13.7	14.3	12.6	9.7	13.6	13.5
otal tree layer cover	38.6	42.2	37.6	44.6	39.1	44.3	38.1	48.1	40.6	43.8	40.1	43.6
otal cover--all layers	64.5	74.4	65.5	84.5	62.3	79.8	63.1	87.2	67.1	80.5	63.2	78.5
ightly burned plots												
d grasses												
arex pensylvanica	15.0	12.7	23.0	22.4	28.0	29.9	33.0	29.1	40.2	28.1	45.9	38.1
upinus albicaulis	5.1	4.3	6.6	7.5	7.7	10.8	9.1	9.9	4.0	3.2	5.9	5.6
ipa occidentalis	.3	.1	1.2	.5	2.1	.6	.8	.3	1.7	1.9	8.0	4.2
estuca arundinacea	0	0	3.7	4.4	7.6	9.0	3.3	4.2	5.1	3.8	3.6	3.5
olium perenne	7.1	8.0	9.6	12.0	6.0	7.9	1.3	3.1	2.0	4.3	1.5	4.3
ther species	.7	.6	.7	.9	.5	.1	.6	.2	1.1	.2	2.3	.5
otal herb layer cover	25.2	22.4	37.5	38.4	44.4	47.5	42.0	38.7	49.2	40.4	59.7	51.6
s												
anothus velutinus	.3	.3	.2	.3	.3	.7	.6	.7	.9	1.0	.8	1.6
ther species	.2	.1	.1	.1	.1	.2	0	0	0	0	0	0
otal shrub layer cover	.5	.4	.3	.4	.4	.9	.6	.7	.9	1.0	.8	1.6
inus contorta	.3	.5	.2	.2	.2	.3	.2	.5	.3	1.3	.5	1.3
otal tree layer cover	.3	.5	.2	.2	.2	.3	.2	.5	.3	1.3	.5	1.3
otal cover--all layers	26.0	23.3	38.0	39.0	45.0	48.7	42.8	39.9	50.4	42.7	61.0	54.5
avily burned plots												
a grasses												
arex pensylvanica	4.4	10.4	10.7	14.6	11.5	16.6	15.4	17.2	17.2	15.3	17.5	15.8
inus albicaulis	3.6	1.2	6.6	3.7	8.9	5.3	9.8	7.3	9.1	6.1	13.4	8.6
ipa occidentalis	0	0	.5	0	.7	0	.9	0	.8	.1	1.9	Trace
estuca arundinacea	0	0	.4	1.7	.6	2.9	0	3.4	Trace	2.6	Trace	3.4
olium perenne	.7	1.6	.8	2.4	.1	3.0	.2	2.4	Trace	1.8	Trace	2.5
ther species	0	.1	0	.2	0	.2	.2	.3	.4	.1	.8	.2
otal herb layer cover	7.7	13.0	15.2	20.5	16.8	25.2	22.0	28.2	23.5	24.9	29.3	29.6
s												
anothus velutinus	.3	.2	.3	.2	.3	.3	.2	.3	.2	.5	.1	.4
otal shrub layer cover	.3	.2	.3	.2	.3	.3	.2	.3	.2	.5	.1	.4
inus contorta	.1	0	0	0	0	0	0	0	0	0	0	0
otal tree layer cover	.1	0	0	0	0	0	0	0	0	0	0	0
otal cover--all layers	8.1	13.2	15.5	20.7	17.1	25.5	22.2	28.5	23.7	25.4	29.4	30.0

The plant species which were important in the early stages of succession after the fire were mostly those present in the preburn stand (table 6). With the exception of snowbrush (*Ceanothus velutinus*), invading species were extremely sparse. Of the species aerially seeded for erosion control, only tall fescue (*Festuca arundinacea*) and perennial ryegrass (*Lolium perenne*) appeared on the burned plots in more than trace amounts. However, even these plants were so scattered that any beneficial soil stabilizing effects were minimal.

DISCUSSION

Hydrophobic soil properties are generally ascribed to organic films which coat soil particles. Although the chemical composition of these coatings is not completely known, they have been variously attributed to products of soil fungi (Bond 1969), products of natural decomposition of plant litter (Bozer et al. 1969), and aliphatic hydrocarbonlike materials produced by heating chaparral litter to temperatures above 300 °C (Savage et al. 1972). The marked resistance to soil wetting observed in our study area appeared to be most directly influenced by lodgepole pine litter. In the unburned portion of the study area, greatest resistance to soil wetting and lowest infiltration rates were observed in those areas where the pine litter was thickest. Apparently most of the resistance to wetting in these unburned soils is confined to the surface inch of mineral soil. As figure 2 indicates, the 0- to 1-inch (0- to 2.5-cm) layer of unburned soil is even more resistant to wetting than that in burned areas. Like other investigators, I can only speculate on the mechanisms responsible for this observed relationship between pine litter and water repellency in the surface soil. Apparently some of the products of needle litter decomposition, when adsorbed on soil particles, bring about marked hydrophobic properties. As DeByle (1973) pointed out in his study in Montana, it is difficult to discern whether the hydrophobic properties are imparted by fungal mycelia, by products of decomposition, or by both.

Pine litter has been found to cause marked water repellency in soils elsewhere in the Western United States. Meeuwig (1971), in his study of infiltration characteristics of granitic soils in the Carson Range of the Sierra Nevada, found continuous layers of water-repellent soil only under pine litter. Other vegetation types (e.g., chaparral) were associated with small patches of water-repellent soils, but not continuous layers.

In the present study, wildfire had pronounced effects on patterns of water repellency in the surface 12 inches (30.5 cm) of soil. Our data indicate that following burning, although the surface inch was less resistant to wetting, wetting resistance was increased below, especially in the 1- to 6-inch (2.5- to 15.2-cm) layers. These results are remarkably similar to the soil wettability patterns observed following fires in the mountains of southern California (DeBano and Krammes 1966, DeBano 1966). There, soil, which before burning was only nonwettable in the surface inch, was found, after burning, to have a wettable 1- to 2-inch (2.5- to 5.1-cm) surface layer underlain by a 2- to 4-inch (5.1- to 10.2-cm) water-repellent layer. Based on these observations and laboratory burning experiments, DeBano (1969b) hypothesized that the downward shift in the water-repellent layer is caused by volatilization of hydrophobic substances during burning and their subsequent condensation in cooler, lower soil layers. Source of these hydrophobic substances was thought to be certain volatile components of chaparral litter. A similar process might also be responsible for causing increased water repellency in

e 2- to 9-inch (5.1- to 22.9-cm) layers
· the soils we studied. In the Airstrip
rn area, however, the probable source
volatile hydrophobic substances is pine
er rather than shrub litter.

There has been virtually no informa-
n on how long fire-induced decreases in
l wettability persist. Most studies have
olved only a single sampling soon after
fire, with very little attention paid to
g-term trends in soil wettability. One
he few workers who has addressed this
oblem is DeByle (1973). In a slash-
rned area in Montana, he found evidence
increased water repellency in the sur-
e soil during the first year after burn-
, but by the second year these changes
wettability were no longer detectable.
our study we found that decreased soil
tability in the 2- to 9-inch (5.1- to
9-cm) soil layers continued at a rela-
ely high level for a period of 5 years
er burning. However, by the 6th year
er the fire, water repellency in the
rned soil areas had decreased to the
nt where values were approaching pre-
in levels.

It is rather difficult to explain the
atively abrupt decrease in resistance
wetting which occurred 6 years after
rning. If leaching or microbial degra-
ion processes are responsible for
moving hydrophobic coatings from soil
rticles, decreases in water repellency
uld be expected to occur more gradually.
owever, at least in the case of the 2- to
-and 4- to 6-inch (5.1- to 10.2- and
02- to 15.2-cm) soil layers in the heavily
rned area, decreases in water repellency
re almost negligible until 1973 (fig. 2).
he 1-year period from 1972 to 1973,
en contact angle value decreased 10
egrees. It is also hard to account for the
pparent increases in water repellency
easured for 1972 samples from burned
as over those collected in 1971. These
increases were especially noticeable in the 6- to 9- and 9- to 12-inch (15.2- to 22.9- and 22.9- to 30.5-cm) layers. If there had been a concomitant decrease in repellency in the upper layers, we could perhaps explain it on the basis of the downward leaching of the hydrophobic substance. However, this seems an untenable hypothesis since repellency in upper layers either increased slightly or remained constant during this same period (fig. 2).

Application of a wetting agent had little measurable effect on soil liquid-solid contact angles and, as far as could be determined, no effect on plant cover. There was some indication that the wetting agent may have increased infiltration rates to some extent, but the sample size was too small to adequately test the significance of these results. Since annual precipitation amounts to some 95 inches (2 413 mm) in the study area, it is easy to understand how the material would be quickly leached from the upper soil profile. However, the wetting agent was applied during the dry summer period; and the 1968 and 1969 soil wettability samples were collected and the infiltration tests conducted soon afterward, or before the heavy fall rains began. Even so, measured effects on soil wettability were minimal. However, as pointed out in the section describing revegetation results, the lack of vegetative response is more easily explained because the wetting agent application was carried out after the period of maximum germination and plant growth. Perhaps if the wetting agent had been applied in the early summer, immediately after snowmelt but before plant growth commenced, there might have been a vegetative response. This is, however, purely conjectural, since the upper soil layers should contain more than adequate supplies of available water at this time.

SUMMARY AND CONCLUSIONS

Moderate resistance to wetting may be a common characteristic of sandy soils in the central Oregon Cascades, even in those areas untouched by recent fires. In the Airstrip Burn we found water repellency of soils in an unburned area to be most pronounced in the surface inch of mineral soil. In most instances the unburned soil below 1 inch (2.5 cm) was at least fairly wettable.

For 6 years, measurements after the Airstrip Burn have shown that the fire appears to have caused increased water repellency in burned soils. Although burned soils were slightly more wettable than unburned soils in the surface inch, substantial increases in water repellency were found for the 1- to 6-inch (2.5- to 15.2-cm) soil depths in burned areas. There was some indication that fire-induced increases in resistance to wetting may have extended as deep as 12 inches (30.5 cm). Soils in both heavily and lightly burned areas showed approximately the same reduction in wettability during the first 2 years after the fire. However, during the 3d and 4th years after the fire, recovery toward preburn soil wettability conditions was considerably more rapid in lightly burned than in heavily burned soils.

Liquid-solid contact angle measurements indicated that decreases in soil wettability persisted in the burned areas for 5 years after the fire. By the 6th year, contact angle values for the burned soil samples were approaching those measured in the unburned soil.

The decreased soil wettability in burned areas was borne out by the results of ring infiltrometer tests. Infiltration rates on burned soils were only about one-third as fast as those measured in unburned areas (about 10 versus 30 inches per hour). Although rates in the lightly burned area were even lower than those in the heavily burned area for the first 3 years after the fire, they consistently increased during the final 3 years of measurements. Even so, 6 years after the fire the average infiltration rate for lightly burned plots was only 13 inches per hour, compared with 32 inches per hour for the unburned soil.

Yearly vegetation inventories showed a much faster rate of revegetation on lightly burned than on heavily burned plots. Six years after the fire, vegetation cover totaled 30 percent in the heavily burned area, 58 percent in the lightly burned, and 71 percent in the unburned area. Most of the species in the burned areas were also present before the fire. Grasses and clover which were aerially seeded soon after the burn contributed only negligible amounts of cover.

In August 1968 and again in June 1969, the wetting agent, Aqua-Gro, was applied to half the plots in each of the three conditions (unburned, lightly burned, and heavily burned). We could detect no effect of these applications on plant growth. Effects of the wetting agent on soil wettability, as assessed by contact angle and infiltration rate measurements, were minimal. Apparently nonionic surfactants offer little promise as a practical method for ameliorating the detrimental soil effects of burning at least in areas receiving sufficient precipitation to leach them from the soil profile.

Following the fire, the Airstrip Burn area contained conspicuous evidences of large-scale overland flow and surface erosion. Heavy fall rains produced numerous examples of rilling and gullying in the burned area. Although this may have been partially caused by the destruction of the discontinuous protective mantle of plants

nd litter, the fire-induced water-repellent oils undoubtedly played a major role. ithout marked resistance to wetting, ese coarse-textured soils would be xpected to have such high infiltration ates that surface runoff would be minimal, ven in bare soil areas. Fortunately, in is case serious consequences of soil osion were minimized due to the gentle pography of the study area. However, ildfires in areas with similar soils on eep slopes could lead to very serious osion problems caused largely by de-eased soil wettability. Since the effects burning on water repellency persist for veral years, it is essential that the land anager act immediately to aid soil stabi-ation as soon as the fire is controlled. areas of high precipitation, such as the egon Cascades, the application of wet-ng agents apparently does not offer much omise as an effective control measure. rhaps the most effective treatment would immediate seeding of well-adapted grass d legume species and liberal application a nitrogen fertilizer. In addition, refer-tilization after a year or two might be neficial.

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Soil wettability characteristics and revegetation trends were studied for 6 years following the 1967 Airstrip Burn. Burning caused an apparent increase in water repellency of the soil at depths of 1-9 inches, which persisted for 5 years after the fire. Application of a wetting agent had little discernible effect on soil wettability and rates of revegetation.

Keywords: Wildfire (-hydrology, soil condition (-forest damage.

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1976

Lumber Yields by the NEW TIMBER CRUISING LOG GRADES for Old-growth Coast Douglas-fir

by
Marlin E. Plank
and
John W. Henley

Pacific Northwest Forest and Range Experiment Station
Forest Service · U. S. Department of Agriculture
Portland, Oregon

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LUMBER YIELDS BY THE NEW TIMBER CRUISING LOG GRADES FOR OLD-GROWTH COAST DOUGLAS-FIR

Reference Abstract

Plank, Marlin E., and John W. Henley
1976. Lumber yields by the new timber cruising log grades for old-growth Coast Douglas-fir. USDA For. Serv. Res. Pap. PNW-203, 30 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Lumber grade yields and recovery ratios obtained for old-growth Coast Douglas-fir logs are presented for the new timber cruising log grades. Lumber yield information is based on nearly 5,000 logs processed through 10 sawmills in Washington, Oregon, and California. Curve relationships are shown for lumber grade recovery over diameter, scale recovery ratio over diameter, lumber recovery factor over diameter, and net Scribner and gross cubic scale defect over diameter for the four log grades. Tables provide information on lumber yield distribution by diameter class and lumber grade in addition to the foregoing.

KEYWORDS: Lumber recovery studies, old-growth Douglas-fir.

RESEARCH SUMMARY

Research Paper PNW-203

1976

This report presents lumber yield information based on a new system of grading old-growth Coast Douglas-fir by four grades. Nearly 5,000 logs were sawn in 10 sawmills throughout Washington, Oregon, and California. Lumber from each was identified and the identity maintained through the shipping tally.

The logs produced 2,699,546 board feet of lumber. About 54 percent of the lumber production was in 2-inch Dimension; 1-inch Board, Shop, and other items thicker than 2 inches accounted for 10, 12, and 24 percent of the total, respectively. Lumber grade yield patterns shown in curve and table form emphasize the need for stratification by log grade and diameter.

Defect deductions averaged 10, 12, and 12 percent, respectively, for grades 1, 2, and 3 logs but increased to 19 percent for grade 4 logs. Curves of defect over diameter are shown for each log grade.

On the average, about 64 percent of the gross cubic content of the log was manufactured into rough green lumber although this depended on the log mix. About 25 percent of this lumber volume was lost as shrinkage and planer shavings. Thus, about 50 percent of the cubic content of the log was finally shipped as lumber. These relationships are shown in tables and curve form. Other tables and curves show lumber grade yield patterns by diameter for the four log grades.

Introduction

New timber cruising grades have been developed for old-growth Coast Douglas-fir (*4,5*). These grades were developed for logs in standing trees. Lumber recovery information obtained for these grades are presented in this report. The information is considered to be representative of Coast Douglas-fir and useful to forest managers, buyers, and timber processors in appraising, harvesting, and processing such timber. The new log grading system for Douglas-fir, on which these recovery data are based, was developed from studies of timber characteristics and their relationships to end-product yield and values.

This report is one of several based on an analysis of timber characteristics and lumber and veneer yields from more than 1,000 trees throughout the Douglas-fir region of Washington, Oregon, and California. Two reports present lumber and veneer yield according to current Forest Service sawmill log-peeler log grading criteria (*3,6*). Veneer recovery information, based on the new timber cruising grades, is presented in another report (*8*).

RECOVERY BASIS

The lumber yield data are based on 4,974 logs sawn at 10 sawmills in California, Oregon, and Washington. These logs came from trees selected from approximately 100 sample areas. The study trees were selected to be representative of trees in each size and quality class of west-side commercial Douglas-fir timber. The total log sample was not intended to be representative of a typical log mix at a mill.

The recovery data are presented on the basis of the sawn log. This approximates the Forest Service cruise log length where grades are applied in 16-foot lengths through the first three 32-foot logs. The sawn logs had the following length distribution:

Log length (Feet)	Number	Percent[1/]
8	11	0.2
10	46	.9
12	260	5.2
14	459	9.2
16	1,736	34.9
17	6	.1
18	719	14.5
20	1,111	22.3
22	144	2.9
24	308	6.2
26	87	1.7
28	15	.3
30	8	.2
32	12	.2
34	36	.7
35	0	0
36	14	.3
38	0	0
40	2	--

Average log length was almost 18 feet.

Logs were bucked for sawing according to practices normally followed at each study mill. The logs were scaled after they were bucked for sawing, normally as they entered the sawmill, by Bureau of Land Management rules.[2/] These scaling rules follow National Forest Log Scaling Handbook rules, except for scale deduction procedures. Volumes are in Scribner Decimal C scale.

[1/] Does not add to 100 due to rounding.

[2/] Bureau of Land Management, Log Scaling Manual Supplements, on file at the Oregon State Office, Portland.

A detailed diagram of size, position, and type of all surface characteristics was prepared for each study log (2). Existing and trial grading specifications were applied to the diagrams to determine the grade of each log. Upon completion of the development and testing of the grading system, the study logs were graded by application of the final specifications (appendix) to these diagrams.

SAWING, SURFACING, AND TALLYING

Equipment, manufacturing methods, and product outturn of the study sawmills were representative of general industry practices in the Coast Douglas-fir region. Mill production equipment included band headsaws, edgers, band resaws, and gang trimmers. The mills cut the logs by their normal manufacturing procedures for producing optimum values of Board, Dimension, Select, and Shop lumber items. The logs were sawn during the period 1964-67.

When study trees were felled and bucked into logs, each log was numbered to identify its origin as to sample area, tree number, and position in the tree. This identity was maintained on each piece of lumber through the manufacturing process to the final point of grading and tally. The lumber was graded by, or under the direct supervision of, a quality supervisor of Western Wood Products Association, West Coast Lumber Inspection Bureau, or Pacific Lumber Inspection Bureau. All study lumber was graded under the West Coast Lumber Inspection Bureau's standard grading and dressing rules (7).

Each piece was tallied by shipping dimension, grade, and log number. In some mills, this tally was made after surfacing; in others, on the green chain. For the latter, the grader "pencil trimmed" where necessary, and the anticipated surfaced tally was recorded. All 2-inch Dimension, Board, and timber items were tallied in a green condition. The condition of the Select and Shop items varied, as noted in table 1. A general summary of the production characteristics of the 10 sawmills is shown in table 1.

Table 1—Manufacturing characteristics of the study sawmills

Study location	Production equipment 1/	Approximate production per 8-hour shift	Lumber items produced				
			Select	Shop	Boards	2-inch Dimension	Timbers
		Thousand board feet					
Washington:							
Northern Washington Cascades	BHS, E, VRS, TS	90	Green	Green	Green	Green	Green
Southern Washington Cascades	BHS, E, GS, TS	100	Green	--	Green	Green	Green
Olympic Peninsula	BHS, E, GS, TS, VRS	160	Green	Green	Green	Green	Green
Oregon:							
Northern Oregon Cascades	BHS, E, HRS, TS	100	Green	--	Green	Green	Green
Central Oregon Cascades	BHS, E, VRS, TS	110	Green	Green	Green	Green	Green
Southern Oregon Cascades	BHS, E, VRS, TS	90	Dry	Dry	Green	Green	--
Oregon coast	BHS, E, VRS, TS	85	Green	Green	Green	Green	Green
California:							
Northern California coast	BHS, E, VRS, GS, TS	100	Green	--	Green	Green	Green
Northern Sierras	BHS, E, GS, TS	75	Dry	Dry	Green	Green	--
Central Sierras	BHS, E, VRS, TS	150	Dry	Dry	Green	Green	--

1/ BHS - band headsaw, E - edger, VRS - vertical band resaw, HRS - horizontal band resaw, TS - trim saws, GS - gang saw.

COMPILATION OF DATA

The tally information obtained for the sawn logs was computed to obtain lumber grade yields in board feet (*1*). The cubic-foot volume of the logs, lumber, sawdust, and residue was also calculated for each log. The gross cubic log volume was computed by the formula:

$$\text{Gross cubic log volume} = 0.001818\ L(D_S^2 + D_S D_L + D_L^2)$$

where: D_S is the log scaling diameter in inches, small end;
D_L is the log scaling diameter in inches, large end; and
L is the log scaling length in feet.

The lumber cubic-foot volumes are based on average rough green dimensions. These average dimensions were obtained from measurements of a selected sample of the lumber during each mill study. The sawdust volumes in cubic feet were calculated from an assumed average saw kerf thickness for each mill and the computed rough green surface area of the lumber from each log. The residue volume in cubic feet is the gross cubic log volume minus lumber and sawdust volumes. Thus, the residue volume includes a small amount of sawdust from the production of slabs, edgings, and trim ends. Note that gross cubic volume is based on scale lengths; an average trim allowance of 6 inches would increase the gross cubic volume of the average log by 2.8 percent, with a corresponding increase in volume of residue.

Results

Total log scale, lumber tally, and cubic-foot volume are summarized by log grade in table 2. These values, as well as the lumber grade yields, are presented by scaling diameter and log grade in the appendix. These tables permit further analysis by those who may be interested and are the basis for subsequent discussion. The recovery ratios are based on totals by log grade from results obtained in 10 sawmills.

LUMBER RECOVERY

The 4,974 logs produced 2,699,546 board feet of lumber. This lumber volume is summarized by thickness, width, and grade in table 3. About 54 percent of the lumber production was in 2-inch Dimension; 1-inch Board, Shop, and other items thicker than 2 inches accounted for 10, 12, and 24 percent of the total, respectively.

Table 2—Total log scale, lumber tally, and cubic volume by log grade

Log grade	Number of logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery ratio[2]	Log	Lumber	Lumber recovery ratio[3]	Sawdust	Residue
		Board feet			Percent	Cubic feet		Percent	Cubic feet	
No. 1	559	526,740	473,640	516,833	109	70,553.17	44,693.02	63	7,445.70	18,414.45
No. 2	1,047	720,460	636,660	712,985	112	97,726.37	61,512.33	63	10,710.76	25,503.28
No. 3	2,210	863,610	760,950	924,627	122	119,961.41	78,500.79	65	13,836.61	27,624.01
No. 4	1,158	535,350	432,340	545,101	126	74,397.17	46,157.12	62	8,155.07	20,084.98
Total or average	4,974	2,646,160	2,303,590	2,699,546	117	362,638.12	230,863.26	64	40,148.14	91,626.72

[1] As scaled by Bureau of Land Management scales, east side log scaling rules, Scribner Decimal C log scale.
[2] Lumber tally volume as percentage of net log scale volume.
[3] Lumber cubic volume as percentage of log cubic volume.

Table 3--Distribution of lumber volume by thickness, width, and grade from 4,974 sawn-length logs

Thickness	Width	Volume	Grade												
			B & Btr Select	C Select	D Select	Moulding	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Select Structural 1/	Construction	Standard	Utility	Economy	All grades
Inches		Board feet	Percent of total lumber volume													
1	2,3,4	48,446	0.17	0.53	0.23	--	--	--	--	--	0.01	0.33	0.20	0.20	0.12	1.79
	6	67,424	.18	.58	.35	--	--	--	--	--	.04	.53	.40	.29	.13	2.50
	8	74,384	.11	.47	.34	--	--	--	--	--	.03	.42	.41	.64	.34	2.76
	10	23,333	.12	.33	.26	--	--	--	--	--	(2/)	.05	.04	.04	.02	.86
	12 & wider	58,790	.53	.74	.67	--	--	--	--	--	(2/)	.09	.05	.08	.02	2.18
	Total	272,377	1.11	2.65	1.85	--	--	--	--	--	.08	1.42	1.10	1.25	.63	10.09
2	2,3,4	207,183	.49	.86	.46	--	--	--	--	--	.46	1.70	1.16	1.62	.92	7.67
	6	251,822	.85	1.12	.39	--	--	--	--	--	.76	1.98	1.50	1.94	.79	9.33
	8	253,864	.36	.51	.26	--	--	--	--	--	1.13	2.40	1.90	2.16	.68	9.40
	10	150,815	.24	.40	.18	--	--	--	--	--	1.32	1.63	1.04	.62	.16	5.59
	12 & wider	579,212	.91	.73	.29	--	--	--	--	--	3.42	6.97	4.50	3.65	.98	21.45
	Total	1,442,896	2.85	3.62	1.58	--	--	--	--	--	7.09	14.68	10.10	9.99	3.53	53.44
3 & 4	4	47,917	.06	.16	.12	--	--	--	--	--	.38	.54	.20	.27	.16	1.78
	6	150,270	.24	.56	.09	--	--	--	--	--	1.12	1.33	.75	.43	.46	5.57
	8	72,330	.17	.15	.03	--	--	--	--	--	.45	.78	.37	.34	.09	2.68
	10	76,840	.46	.17	.02	--	--	--	--	--	.90	.70	.53	.06	.01	2.85
	12 & wider	175,167	1.90	.34	.05	--	--	--	--	--	.82	1.48	.88	.97	.15	6.49
	Total	522,524	3.53	1.47	.20	--	--	--	--	--	3.67	4.83	2.73	2.07	.87	19.37
5 & thicker	6	43,584	.11	.07	(2/)	--	--	--	--	--	.46	.66	.27	.03	.01	1.61
	8	24,642	.05	.07	(2/)	--	--	--	--	--	.37	.25	.03	.14	0	.91
	10	11,290	.10	.01	0	--	--	--	--	--	.07	.21	.03	0	0	.42
	12 & wider	50,634	.18	.02	0	--	--	--	--	--	.47	.56	.19	.45	(2/)	1.87
	Total	130,150	.44	.17	0	--	--	--	--	--	1.37	1.68	.52	.62	.01	4.81
1 (4/4)	Random	46,710	--	--	--	0.93	0.25	0.30	0.25	(2/)	--	--	--	--	--	1.73
1-1/4 (5/4)	Random	128,574	--	--	--	1.43	.13	.85	1.88	0.47	--	--	--	--	--	4.76
1-1/2 (6/4)	Random	46,420	--	--	--	.44	.15	.44	.58	.11	--	--	--	--	--	1.72
1-5/8	Random	47,659	--	--	--	0	.32	.51	.71	.23	--	--	--	--	--	1.77
	Random	62,236	--	--	--	.07	.87	.59	.66	.12	--	--	--	--	--	2.31
	Total	331,599	--	--	--	2.87	1.72	2.69	4.08	.93	--	--	--	--	--	12.29
Total all items		2,699,546	7.93	7.91	3.63	2.87	1.72	2.69	4.08	.93	12.21	22.61	14.45	13.93	5.04	100.00

1/ 1-inch boards are termed Select Merchantable.

2/ Percentage is less than 0.005.

The influence of log quality and size on lumber yield is shown in figure 1. The variability that occurs in lumber yield has been smoothed by curving to indicate yield patterns. There was a significant increase in the proportion of Select grade lumber as log size increased. A reverse pattern is evident for Standard and Better lumber. The need for stratification by log grade and diameter is emphasized by the yield patterns.

DEFECT

The average defect deduction for the 10 studies was 13 percent. As expected, the smaller logs contained the least defect and the deduction increased with an increase in diameter. Defect deductions for grades 1, 2, and 3 logs averaged 10, 12, and 12 percent, respectively, but increased to 19 percent for grade 4 logs. Defect in grades 3 and 4 logs increased with increased diameter. This is to be expected because logs with scars containing evidence of rot were kept out of the higher grades. The relationship between defect percent and diameter for each log grade and all grades combined is shown in figure 2. There was a significant difference (5-percent level) among the relationships of defect percent over diameter for the various log grades.

LUMBER RECOVERY RATIOS (OVERRUN)

The ratios of lumber tally to net scale, commonly referred to as overrun, are related to log size and defect. The curves shown in figure 3 result from fitting quadratic or 2d-degree equations to the

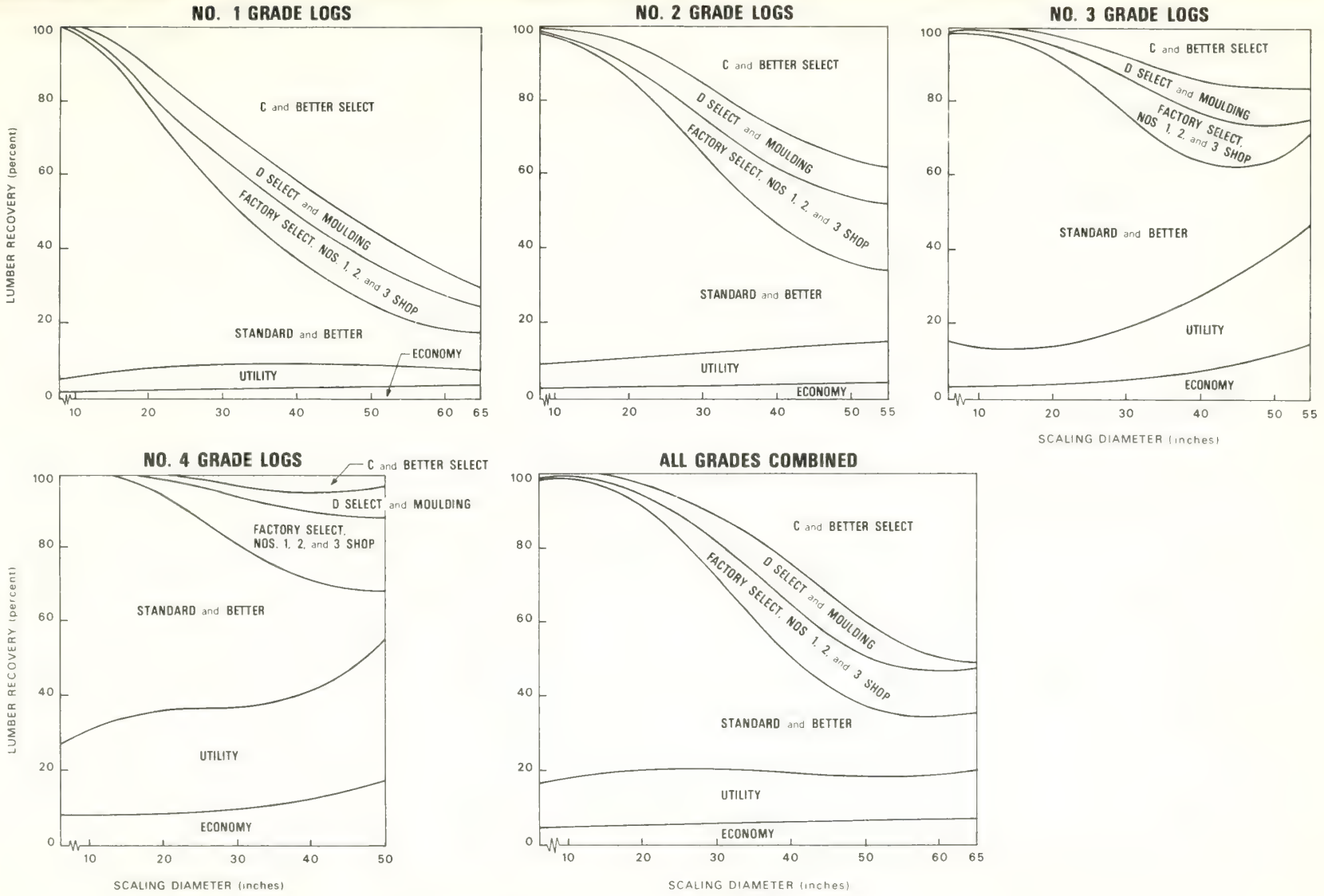

Figure 1.--Lumber recovery by scaling diameter and log grade.

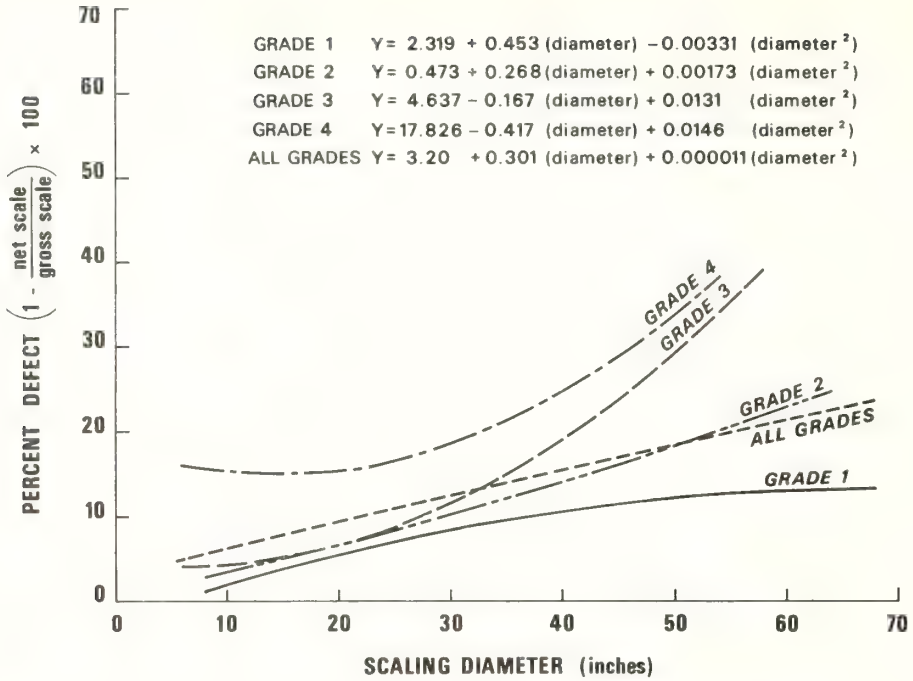
GRADE 1 Y= 2.319 + 0.453 (diameter) −0.00331 (diameter²)
GRADE 2 Y= 0.473 + 0.268 (diameter) + 0.00173 (diameter²)
GRADE 3 Y= 4.637 − 0.167 (diameter) + 0.0131 (diameter²)
GRADE 4 Y=17.826 − 0.417 (diameter) + 0.0146 (diameter²)
ALL GRADES Y= 3.20 + 0.301 (diameter) + 0.000011 (diameter²)
PERCENT DEFECT (1 - net scale / gross scale) × 100
SCALING DIAMETER (inches)
GRADE 4
GRADE 3
GRADE 2
ALL GRADES
GRADE 1
0
10
20
30
40
50
60
70

Figure 2.--Relationship of log scale defect to scaling scaling diameter.

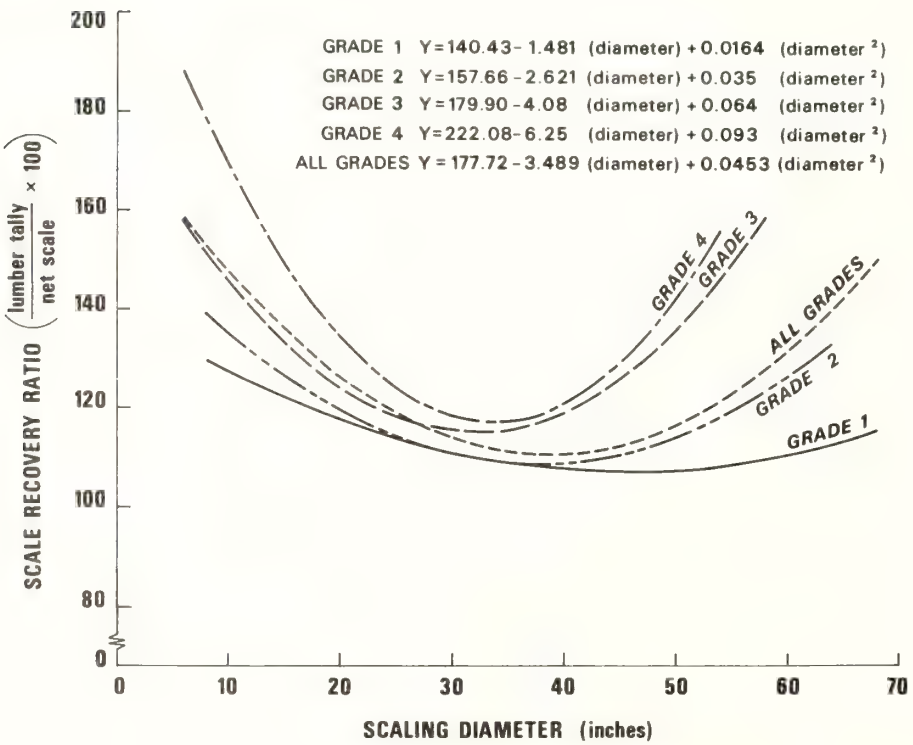

Figure 3.--Relationship of board-foot lumber tally-net scale recovery ratio to scaling diameter of logs.

ratios. These ratios tend to decrease as log diameter approaches 30-40 inches, where they begin to swing upward. This upward trend apparently occurs because lumber is recovered from portions of the log which contain defect and for which a scale deduction has been made. The board-foot lumber tally-net scale ratios show a significant difference (5-percent level) among the relationships of the ratios over diameter for the various log grades.

CUBIC RATIOS

The relationship of the lumber cubic volume recovery ratio to scaling diameter is shown in figure 4. This relationship has an opposite trend to that of the board-foot lumber tally ratio. The cubic ratio tends to increase to about 35 inches and then trends downward. On the average, about 64 percent of the gross cubic content of the log was manufactured into rough green lumber. About 25 percent of this lumber volume was lost as shrinkage and planer shavings. Because of this, about 50 percent of the cubic log content was shipped as lumber.

The relationship of board-foot lumber yield per gross cubic foot of log input to scaling diameter is snown in figure 5. The cubic-volume curves show a significant difference among the relationships of lumber recovery over diameter for the various grades at the 5-percent level.

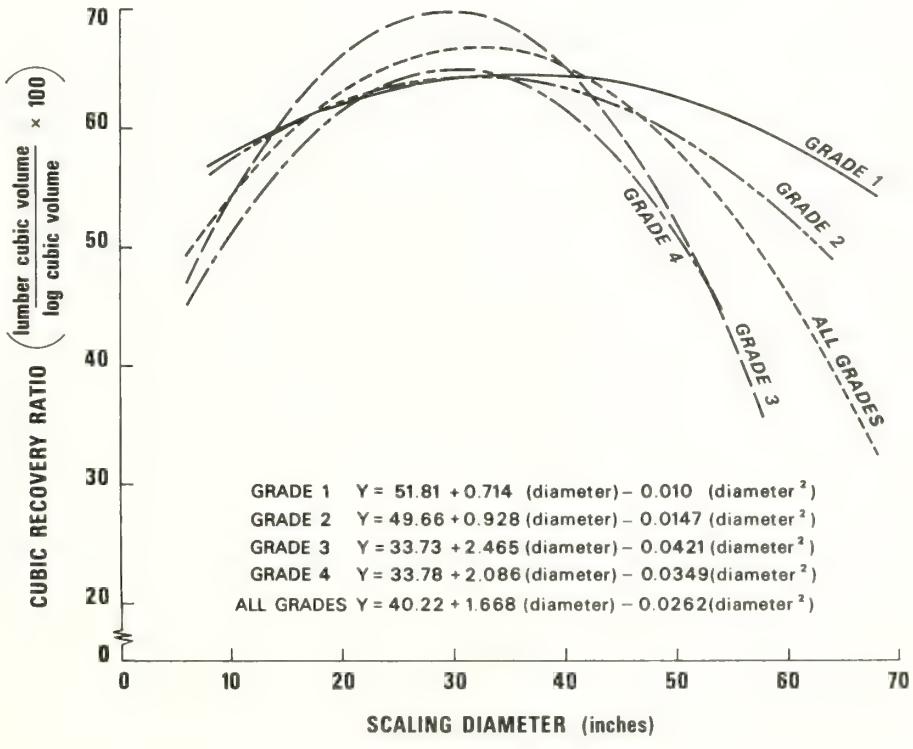

Figure 4.--Relationship of lumber cubic volume recovery ratio to scaling diameter of logs.

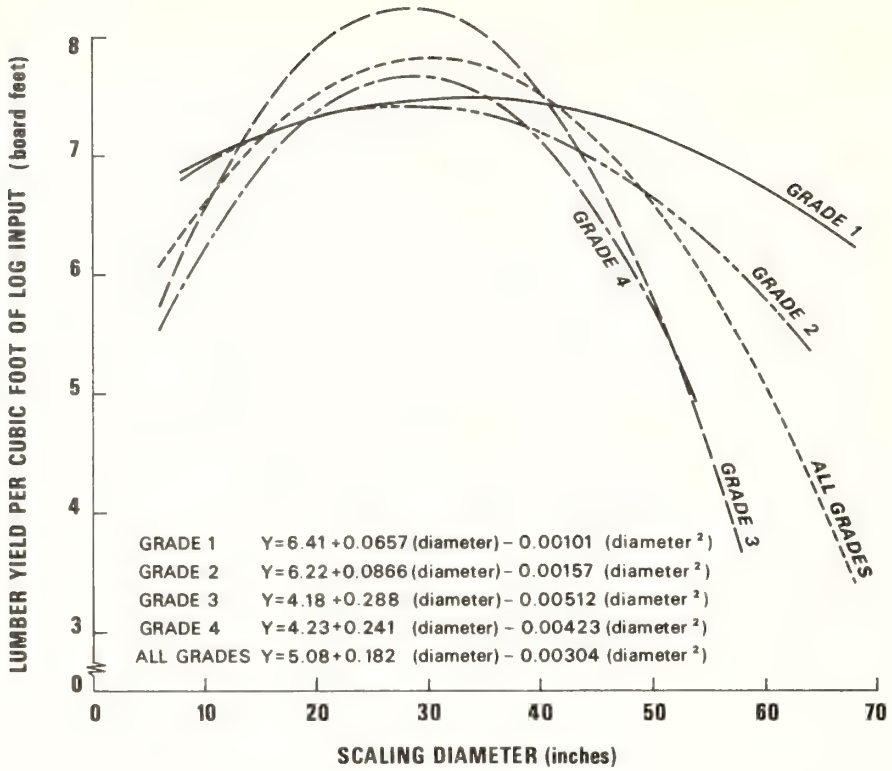

Figure 5.--Relationship of board-foot yield per cubic foot of log input to scaling diameter.

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METRIC EQUIVALENTS

Lumber size (Inches)	Metric equivalent[1/] (Millimeters)
1	25.4 (25)
5/4	31.7 (32)
6/4	38.1 (38)
1-5/8	41.3 (41)
2	50.8 (50)
3	76.2 (75)
4	101.6 (100)
5	127.0 (125)
6	152.4 (150)
8	203.2 (200)
10	254.0 (250)
12	304.8 (300)

U.S. lengths (Feet)	Metric equivalent[1/] (Meters)	U.S. lengths (Feet)	Metric equivalent[1/] (Meters)
8	2.44 (2.4)	26	7.92 (7.8)
10	3.05 (3.0)	28	8.53 (8.4)
12	3.66 (3.6)	30	9.14 (9.0)
14	4.27 (4.2)	32	9.75 (9.6)
16	4.88 (4.8)	34	10.36 (10.2)
18	5.49 (5.4)	36	10.97 (10.8)
20	6.10 (6.0)	38	11.58 (11.4)
22	6.71 (6.6)	40	12.19 (12.0)
24	7.32 (7.2)		

[1/] Figures in parentheses represent nominal sizes used in European trading.

Appendix

Tables 4 - 8. Log scale, lumber tally, and cubic volumes by scaling diameter for each log grade.

Tables 9 - 13. Lumber grade yields by scaling diameter for each log grade.

Tables 14 - 18. Cubic volumes by scaling diameter for each log grade (metric units).

The New Grading Rules
- General Specifications
- Definitions of Grading Characteristics
- Application of Grades

A Summary of Specifications for the New Timber Cruising Grades for Coast Douglas-fir.

Table 4—Log scale, lumber tally, and cubic volumes by scaling diameter, log grade No. 1

Log scaling diameter (inches)	Number of logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery ratio[2]	Log	Lumber	Lumber recovery ratio[3]	Sawdust	Residue
		Board feet			Percent	Cubic feet		Percent	Cubic feet	
8	1	30	30	29	97	7.10	2.29	32	0.41	4.40
9	1	30	30	35	117	6.19	2.98	48	.54	2.67
10	5	320	310	401	129	54.95	33.64	61	5.98	15.33
11	7	530	520	709	136	101.00	59.08	58	10.60	31.32
12	5	400	400	599	150	74.23	50.40	68	9.10	14.73
13	9	1,000	1,000	1,236	124	182.30	104.33	57	15.22	62.75
14	8	970	950	1,161	122	181.22	98.33	54	15.53	67.36
15	12	2,120	2,090	2,431	116	334.36	204.84	61	32.55	96.97
16	9	1,720	1,640	2,096	128	265.76	176.77	67	26.26	62.73
17	12	2,540	2,320	2,873	124	423.93	242.48	57	36.99	144.46
18	9	1,950	1,920	2,256	117	303.70	190.97	63	30.45	82.28
19	10	2,550	2,350	2,758	117	388.84	230.18	59	38.35	120.31
20	12	3,690	3,230	3,774	117	550.47	323.33	59	52.55	174.59
21	17	6,340	6,100	6,814	112	859.94	582.98	68	88.10	188.86
22	9	3,690	3,690	4,126	112	519.49	353.10	68	55.20	111.19
23	17	7,090	6,520	7,250	111	1,012.04	611.78	60	99.97	300.29
24	10	4,580	4,130	4,748	115	653.48	405.43	62	66.61	181.44
25	13	6,840	6,230	7,182	115	949.38	608.09	64	99.12	242.17
26	19	10,170	9,580	10,323	108	1,407.68	883.38	63	140.13	384.17
27	14	8,290	7,420	7,769	105	1,039.70	669.27	64	113.71	256.72
28	14	9,780	9,460	10,273	109	1,299.09	877.91	68	132.58	288.60
29	18	11,330	10,190	12,127	119	1,566.34	1,044.83	67	188.82	332.69
30	19	14,410	13,290	14,072	106	1,880.11	1,211.58	64	185.35	483.18
31	11	9,510	8,920	9,754	109	1,294.90	836.61	65	124.90	333.39
32	20	15,070	14,260	15,098	106	2,009.02	1,299.56	65	215.10	494.36
33	18	15,980	14,550	16,420	113	2,265.50	1,407.46	62	248.37	609.67
34	13	10,800	10,060	10,608	105	1,492.57	922.99	62	153.05	416.53
35	21	20,050	18,050	20,550	114	2,761.08	1,782.84	65	305.54	672.70
36	19	19,670	17,390	18,579	107	2,564.67	1,614.96	63	279.91	669.80
37	19	21,660	19,710	20,957	106	2,863.20	1,814.89	63	324.41	723.90
38	20	24,440	21,450	24,261	113	3,403.96	2,086.61	61	359.69	957.66
39	16	18,960	16,570	19,033	115	2,530.94	1,652.24	65	286.71	591.99
40	17	21,450	18,250	20,225	111	2,703.70	1,785.16	66	323.52	595.02
41	17	21,750	18,860	19,870	105	2,864.08	1,728.81	60	290.86	844.41
42	11	15,520	13,440	14,850	110	1,959.80	1,289.80	66	214.40	455.60
43	15	24,470	22,500	23,875	106	3,139.15	2,071.96	66	335.27	731.92
44	12	18,670	17,270	18,609	108	2,405.62	1,638.42	68	273.46	493.74
45	9	14,730	13,150	14,589	111	1,981.24	1,265.61	64	233.24	482.39
46	8	12,110	11,510	11,646	101	1,535.21	1,025.29	67	180.58	329.34
47	10	17,410	15,700	17,208	110	2,300.69	1,494.47	65	250.68	555.54
48	13	25,520	22,930	23,774	104	3,404.35	2,083.55	61	357.35	963.45
49	7	14,720	13,600	14,897	110	1,984.74	1,286.80	65	199.30	498.64
50	3	5,150	4,940	4,667	94	640.15	411.99	64	75.29	152.87
51	4	8,760	8,090	9,254	114	1,182.77	794.22	67	118.08	270.47
52	7	14,150	11,190	12,254	110	1,837.80	1,069.80	58	191.97	576.03
53	2	4,200	2,690	3,550	132	629.94	311.89	50	59.95	258.10
54	5	11,190	10,250	10,520	103	1,471.77	913.41	62	143.35	415.01
55	4	12,430	11,350	11,650	103	1,628.03	1,003.09	62	137.65	487.29
56	1	2,500	1,840	1,836	100	328.63	153.17	47	24.75	150.71
57	2	4,570	4,020	4,445	111	593.07	381.29	64	53.37	158.41
58	--	--	--	--	--	--	--	--	--	--
59	2	5,880	5,210	5,526	106	748.52	483.56	65	87.54	177.42
60	--	--	--	--	--	--	--	--	--	--
61	--	--	--	--	--	--	--	--	--	--
62	1	3,620	2,940	3,486	119	432.99	291.87	67	38.41	102.71
63	--	--	--	--	--	--	--	--	--	--
64	1	3,870	3,270	3,602	110	475.31	301.06	63	43.05	131.20
65	1	3,190	2,800	2,672	95	434.62	228.55	53	31.33	174.74
66	--	--	--	--	--	--	--	--	--	--
67	--	--	--	--	--	--	--	--	--	--
68	1	4,370	3,480	3,526	101	623.85	293.12	47	40.50	290.23
Total or average	559	526,740	473,640	516,833	109	70,553.17	44,693.02	63	7,445.70	18,414.45

[1] As scaled by Bureau of Land Management scaler, east side log scaling rules, Scribner Decimal C log scale.

[2] Lumber tally volume as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Table 5—Log scale, lumber tally, and cubic volumes by scaling diameter, log grade No. 2

Log scaling diameter (inches)	Number of logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery ratio[2]	Log	Lumber	Lumber recovery ratio[3]	Sawdust	Residue
		Board feet			Percent	Cubic feet		Percent	Cubic feet	
8	4	80	80	113	141	21.20	9.47	45	1.87	9.86
9	9	380	380	628	165	85.25	52.55	62	9.24	23.46
10	14	890	830	1,227	148	162.57	103.19	63	16.51	42.87
11	15	1,100	1,020	1,344	132	215.46	112.22	52	19.00	84.24
12	21	1,860	1,780	2,515	141	346.72	209.77	61	36.35	100.60
13	22	2,380	2,280	2,867	126	414.76	238.33	57	40.90	135.53
14	27	3,500	3,390	4,209	124	608.62	348.87	57	60.19	199.56
15	17	2,640	2,360	2,939	125	429.75	245.70	57	37.84	146.21
16	24	4,400	4,110	4,918	120	686.25	415.30	61	65.20	205.75
17	25	5,310	5,130	6,249	122	830.01	520.47	63	81.39	228.15
18	29	7,020	6,630	8,067	122	1,100.77	676.11	61	110.05	314.61
19	30	7,890	7,420	8,840	119	1,197.76	745.94	62	119.96	331.86
20	33	10,740	10,350	11,339	110	1,498.34	958.11	64	159.52	380.71
21	41	14,020	13,160	14,578	111	2,040.53	1,235.99	61	210.55	593.99
22	39	14,420	13,470	15,516	115	2,062.41	1,309.75	64	214.86	537.80
23	40	17,160	15,550	18,176	117	2,346.97	1,535.69	65	257.11	554.17
24	35	17,050	15,930	18,285	115	2,450.93	1,553.93	63	273.25	623.75
25	41	22,060	20,390	22,857	112	3,013.53	1,945.63	65	336.48	731.42
26	38	20,940	19,460	21,778	112	2,769.10	1,847.91	67	309.57	611.62
27	38	24,630	23,010	24,854	108	3,281.64	2,122.60	65	361.86	797.18
28	42	26,480	24,080	25,979	108	3,549.74	2,229.36	63	387.80	932.58
29	41	29,780	27,460	30,603	111	3,912.97	2,631.36	67	443.61	838.00
30	31	22,080	19,690	22,244	113	3,035.65	1,925.61	63	350.40	759.64
31	45	35,630	30,870	34,325	111	4,702.95	2,987.65	64	517.29	1,198.01
32	34	27,850	25,650	27,321	107	3,643.60	2,360.18	65	395.66	887.76
33	38	32,860	28,410	32,690	115	4,513.72	2,828.45	63	495.57	1,189.70
34	34	32,680	29,500	32,594	110	4,507.64	2,820.53	63	473.98	1,213.13
35	40	39,890	34,910	39,714	114	5,589.02	3,436.14	61	639.36	1,513.52
36	22	21,400	18,960	20,846	110	2,880.62	1,815.37	63	312.71	752.54
37	27	30,100	25,040	29,099	116	3,933.40	2,530.73	64	430.50	972.17
38	20	22,640	18,350	22,226	121	3,067.71	1,920.69	63	354.39	792.63
39	18	27,120	23,870	26,765	112	3,747.38	2,325.48	62	453.52	968.38
40	17	26,390	21,760	27,105	125	3,399.12	2,346.01	69	413.12	639.99
41	13	20,110	16,760	18,625	111	2,782.16	1,629.96	59	300.69	851.51
42	11	14,740	13,660	13,877	102	1,843.41	1,237.82	67	229.52	376.07
43	13	20,260	17,840	17,489	98	2,566.24	1,535.03	60	281.46	749.75
44	9	14,040	10,650	10,915	102	1,850.44	959.14	52	205.45	685.85
45	12	21,530	18,320	20,520	112	2,769.97	1,768.59	64	275.48	725.90
46	6	9,720	8,220	9,040	110	1,301.98	796.93	61	159.82	345.23
47	6	11,240	9,930	10,940	110	1,508.36	981.56	65	180.01	346.79
48	6	11,780	9,920	10,547	106	1,478.22	915.35	62	138.76	424.11
49	5	10,110	8,640	9,302	108	1,296.67	814.17	63	124.93	357.57
50	8	15,690	13,370	14,269	107	1,979.61	1,260.90	64	234.25	484.46
51	1	1,950	1,950	1,912	98	254.73	163.11	64	22.37	69.25
52	1	1,770	1,700	1,377	81	210.47	124.39	59	21.68	64.40
53	1	2,370	1,800	1,879	104	336.97	163.35	48	24.47	149.15
54	2	4,640	2,730	2,616	96	565.88	224.87	40	34.46	306.55
55	--	--	--	--	--	--	--	--	--	--
56	--	--	--	--	--	--	--	--	--	--
57	--	--	--	--	--	--	--	--	--	--
58	--	--	--	--	--	--	--	--	--	--
59	1	3,270	2,270	3,224	142	399.35	271.29	68	35.03	93.03
60	--	--	--	--	--	--	--	--	--	--
61	--	--	--	--	--	--	--	--	--	--
62	--	--	--	--	--	--	--	--	--	--
63	--	--	--	--	--	--	--	--	--	--
64	1	3,870	3,620	3,643	101	535.82	320.78	60	52.77	162.27
Total or average	1,047	720,460	636,660	712,985	112	97,726.37	61,512.33	63	10,710.76	25,503.28

[1] As scaled by Bureau of Land Management scaler, east side log scaling rules, Scribner Decimal C log scale.

[2] Lumber tally volume as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Table 6—Log scale, lumber tally, and cubic volumes by scaling diameter, log grade No. 3

Log scaling diameter (inches)	Number of logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery ratio[2]	Log	Lumber	Lumber recovery ratio[3]	Sawdust	Residue
		- - - - *Board feet* - - - -			*Percent*	- - - *Cubic feet* - - -		*Percent*	- - - *Cubic feet* - - -	
6	42	920	880	1,351	154	265.40	113.80	43	21.85	129.75
7	34	1,030	990	1,324	134	242.58	110.95	46	22.02	109.61
8	86	2,610	2,540	4,228	166	751.85	349.76	47	67.21	334.88
9	91	3,710	3,570	5,555	156	920.96	460.27	50	88.93	371.76
10	103	5,980	5,710	7,940	139	1,218.58	656.69	54	123.45	438.44
11	100	7,110	6,900	9,902	144	1,436.01	824.54	57	153.27	458.20
12	105	9,210	8,870	11,886	134	1,695.49	984.92	58	180.25	530.32
13	100	10,540	9,950	13,915	140	1,885.88	1,148.53	61	205.23	532.12
14	98	12,150	11,400	15,994	140	2,146.81	1,320.03	61	233.44	593.34
15	87	13,250	12,480	15,821	127	2,126.96	1,309.67	62	223.83	593.46
16	108	19,390	18,580	24,901	134	3,085.80	2,047.32	66	356.75	681.73
17	75	15,550	14,800	19,231	130	2,424.69	1,603.47	66	268.84	552.38
18	103	25,260	23,560	29,629	126	3,721.34	2,457.24	66	423.58	840.52
19	84	22,990	21,280	26,532	125	3,335.53	2,209.54	66	367.30	758.69
20	95	30,440	28,640	34,326	121	4,242.02	2,865.85	68	490.82	885.35
21	66	24,090	22,190	27,079	122	3,357.61	2,277.53	68	378.91	701.17
22	73	28,750	26,270	32,399	123	4,006.91	2,725.31	68	453.62	827.98
23	74	32,660	29,830	35,377	119	4,391.09	2,976.32	68	502.38	912.39
24	71	33,760	32,390	37,744	117	4,613.56	3,195.62	69	543.61	874.33
25	65	36,790	34,090	37,919	111	4,836.42	3,238.53	67	515.98	1,081.91
26	61	37,160	32,920	38,026	116	4,847.36	3,218.62	66	570.87	1,057.87
27	51	34,120	31,210	34,867	112	4,369.70	2,976.82	68	532.47	860.41
28	47	30,760	28,080	31,725	113	4,026.08	2,688.89	67	460.53	876.66
29	47	32,610	29,160	35,106	120	4,381.26	3,001.27	69	513.44	866.55
30	38	29,210	26,140	30,881	118	3,860.07	2,649.79	69	499.53	710.75
31	34	29,240	25,830	29,923	116	3,743.08	2,576.04	69	454.48	712.56
32	34	31,050	26,160	32,853	126	4,249.37	2,808.66	66	497.42	943.29
33	35	31,970	27,840	32,184	116	4,202.53	2,758.12	66	497.98	946.43
34	34	33,010	29,030	35,260	121	4,565.23	3,027.91	66	536.73	1,000.59
35	20	20,870	18,110	21,664	120	2,798.70	1,853.66	66	340.89	604.15
36	24	24,550	20,740	24,926	120	3,296.72	2,146.81	65	378.76	771.15
37	23	28,520	25,120	29,346	117	3,593.12	2,547.00	71	468.80	577.32
38	16	20,370	16,100	20,290	126	2,648.94	1,753.95	66	318.18	576.81
39	15	21,010	17,310	20,831	120	2,775.75	1,801.20	65	309.43	665.12
40	13	16,350	13,630	16,660	122	2,103.90	1,427.23	68	272.05	404.62
41	10	15,800	13,630	15,814	116	2,068.07	1,370.17	66	250.44	447.46
42	10	16,580	12,100	14,916	123	2,146.64	1,289.38	60	250.86	606.40
43	4	5,940	3,490	4,769	137	766.01	405.94	53	75.12	284.95
44	6	10,270	8,860	9,702	110	1,294.18	851.02	66	159.18	283.98
45	8	15,110	11,180	14,444	129	2,045.97	1,260.05	62	209.49	576.43
46	3	5,660	4,960	4,490	91	678.18	398.49	59	72.87	206.82
47	5	8,910	6,240	8,289	133	1,158.20	709.65	61	165.30	283.25
48	1	2,940	2,160	3,156	146	391.82	268.57	69	41.66	81.59
49	1	2,020	1,510	1,756	116	240.56	158.44	66	32.10	50.02
50	2	3,740	2,020	3,017	149	486.45	252.03	52	38.76	195.66
51	3	6,810	4,340	5,921	136	850.91	502.93	59	97.84	250.14
52	--	--	--	--	--	--	--	--	--	--
53	1	2,630	1,870	2,587	138	342.41	222.23	65	50.57	69.61
54	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--
56	3	7,060	4,710	5,992	127	951.39	514.78	54	98.30	338.31
57	--	--	--	--	--	--	--	--	--	--
58	1	3,150	1,760	2,179	124	373.32	185.25	50	21.29	166.78
Total or average	2,210	863,610	760,950	924,627	122	119,961.41	78,500.79	65	13,836.61	27,624.01

[1] As scaled by Bureau of Land Management scaler, east side log scaling rules, Scribner Decimal C log scale.

[2] Lumber tally volume as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Table 7—Log scale, lumber tally, and cubic volumes by scaling diameter, log grade No. 4

Log scaling diameter (inches)	Number of logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery ratio[2]	Log	Lumber	Lumber recovery ratio[3]	Sawdust	Residue
		Board feet			Percent	Cubic feet		Percent	Cubic feet	
6	6	180	120	254	212	60.02	21.45	36	4.13	34.44
7	1	30	20	82	410	11.24	6.99	62	1.30	2.95
8	14	450	430	861	200	134.81	71.81	53	12.19	50.81
9	22	1,350	1,240	1,901	153	326.67	158.32	48	28.64	139.71
10	22	1,250	1,150	1,694	147	309.70	138.22	45	28.28	143.20
11	30	2,450	2,000	3,205	160	537.14	264.83	49	51.42	220.89
12	37	3,080	2,580	4,348	168	683.60	360.74	53	65.41	257.45
13	40	4,720	4,180	6,184	148	914.27	513.99	56	90.39	309.89
14	49	6,210	5,120	8,458	165	1,181.57	693.85	59	128.58	359.14
15	51	7,920	6,780	9,688	143	1,355.47	799.08	59	143.51	412.88
16	53	9,730	8,270	12,372	150	1,670.70	1,019.17	61	184.89	466.64
17	49	10,480	8,610	12,296	143	1,760.41	1,034.28	59	174.60	551.53
18	53	12,690	10,730	14,467	135	2,002.03	1,197.74	68	197.31	606.98
19	52	14,570	11,930	16,309	137	2,269.80	1,345.17	59	226.49	698.14
20	66	21,220	17,010	22,910	135	3,086.45	1,921.59	62	323.07	841.79
21	45	15,030	12,910	17,009	132	2,188.37	1,402.49	64	257.95	527.93
22	53	19,520	16,570	21,202	128	2,870.41	1,753.22	61	327.11	790.08
23	43	18,930	15,550	20,086	129	2,628.01	1,707.89	65	313.35	606.77
24	44	19,950	16,940	21,541	127	2,822.10	1,818.24	64	309.16	694.70
25	48	22,910	18,570	23,587	127	3,074.40	1,970.06	64	340.37	763.97
26	43	23,800	19,310	24,385	126	3,188.73	2,053.70	64	369.13	765.90
27	43	25,710	21,110	25,426	120	3,297.18	2,170.02	66	360.05	767.11
28	39	26,930	22,780	26,260	115	3,511.03	2,231.37	64	403.93	875.73
29	31	20,970	18,300	21,951	120	2,805.03	1,875.24	67	343.25	586.54
30	23	16,800	14,340	16,263	113	2,232.38	1,371.92	61	257.93	602.53
31	29	26,720	20,970	24,978	119	3,523.97	2,141.98	61	344.52	1,037.47
32	33	26,910	22,510	26,688	119	3,578.13	2,287.81	64	405.94	884.38
33	20	17,560	14,440	17,173	119	2,347.44	1,488.58	63	265.33	593.53
34	19	17,440	14,900	17,474	117	2,346.23	1,513.66	65	272.85	559.72
35	15	14,550	12,310	15,758	128	1,926.29	1,337.30	69	228.31	360.68
36	16	18,870	15,760	18,721	119	2,467.41	1,610.85	65	274.26	582.30
37	8	10,420	7,900	9,648	122	1,289.45	815.23	63	140.11	334.11
38	11	13,160	10,300	11,441	111	1,636.41	985.28	60	175.42	475.71
39	11	15,960	13,000	14,907	115	2,037.75	1,289.34	63	254.42	493.99
40	8	10,950	7,920	8,654	109	1,346.74	740.23	55	111.27	495.24
41	5	9,230	6,640	8,444	127	1,143.10	726.11	64	134.21	282.78
42	5	7,840	4,790	6,070	127	969.40	513.24	53	82.67	373.49
43	5	8,730	6,210	7,883	127	1,046.36	682.15	65	105.17	259.04
44	1	1,110	740	922	125	129.61	83.42	64	19.72	26.47
45	7	12,300	7,480	10,061	135	1,555.70	878.04	56	173.88	503.78
46	3	4,960	3,720	4,529	122	633.66	369.49	58	72.12	192.05
47	1	2,810	950	1,213	128	377.07	102.79	27	20.31	253.97
48	--	--	--	--	--	--	--	--	--	--
49	--	--	--	--	--	--	--	--	--	--
50	1	1,870	1,190	1,433	120	236.08	135.84	58	33.46	66.78
51	--	--	--	--	--	--	--	--	--	--
52	1	2,530	1,640	2,402	146	318.23	207.56	65	41.10	69.57
53	1	2,370	1,220	2,363	194	302.61	201.10	66	22.42	79.09
54	1	2,180	1,170	1,600	137	264.01	145.74	55	35.14	83.13
Total or average	1,158	535,350	432,340	545,101	126	74,397.17	46,157.12	62	8,155.07	20,084.98

[1] As scaled by Bureau of Land Management scaler, east side log scaling rules, Scribner Decimal C log scale.

[2] Lumber tally volume as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Table 8—Log scale, lumber tally, and cubic volumes by scaling diameter for all log grades

Log scaling diameter (inches)	Number of logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery ratio[2]	Log	Lumber	Lumber recovery ratio[3]	Sawdust	Residue
		Board feet			*Percent*	*Cubic feet*		*Percent*	*Cubic feet*	
6	48	1,100	1,000	1,605	160	325.42	135.25	42	25.98	164.19
7	35	1,060	1,010	1,406	139	253.82	117.94	46	23.32	112.56
8	105	3,170	3,080	5,231	170	914.96	433.33	47	81.68	399.95
9	123	5,470	5,220	8,119	156	1,339.07	674.12	50	127.35	537.60
10	144	8,440	8,000	11,262	141	1,745.80	931.74	53	174.22	639.84
11	152	11,190	10,440	15,160	145	2,289.61	1,260.67	55	234.29	794.65
12	168	14,550	13,630	19,348	142	2,800.04	1,605.83	57	291.11	903.10
13	171	18,640	17,410	24,202	139	3,397.21	2,005.18	59	351.74	1,040.29
14	182	22,830	20,860	29,822	143	4,118.22	2,461.08	60	437.74	1,219.40
15	167	25,930	23,710	30,879	130	4,246.54	2,559.29	60	437.73	1,249.52
16	194	35,240	32,600	44,287	136	5,708.51	3,658.56	64	633.10	1,416.85
17	161	33,880	30,860	40,649	132	5,439.04	3,400.70	63	561.82	1,476.52
18	194	46,920	42,840	54,419	127	7,127.84	4,522.06	63	761.39	1,844.39
19	176	48,000	42,980	54,439	127	7,191.93	4,530.83	63	752.10	1,909.00
20	206	66,090	59,050	72,349	123	9,377.28	6,068.88	65	1,025.96	2,282.44
21	169	59,480	54,360	65,480	120	8,446.45	5,498.99	65	935.51	2,011.95
22	174	66,380	60,000	73,243	122	9,459.22	6,141.38	65	1,050.79	2,267.05
23	174	75,840	67,450	80,889	120	10,378.11	6,831.68	66	1,172.81	2,373.62
24	160	75,340	69,390	82,318	119	10,540.07	6,973.22	66	1,192.63	2,374.22
25	167	88,600	79,280	91,545	115	11,873.73	7,762.31	65	1,291.95	2,819.47
26	161	92,070	81,270	94,512	116	12,212.87	8,003.61	66	1,389.70	2,819.56
27	146	92,750	82,750	92,916	112	11,988.22	7,938.71	66	1,368.09	2,681.42
28	142	93,950	84,400	94,237	112	12,385.94	8,027.53	65	1,384.84	2,973.57
29	137	94,690	85,110	99,787	117	12,665.60	8,552.70	68	1,489.12	2,623.78
30	111	82,500	37,460	83,460	114	11,008.21	7,158.90	65	1,293.21	2,556.10
31	119	101,100	86,590	98,980	114	13,264.90	8,542.28	64	1,441.19	3,281.43
32	121	100,880	88,580	101,960	115	13,480.12	8,756.21	65	1,514.12	3,209.79
33	111	98,370	85,240	98,467	116	13,329.19	8,482.61	64	1,507.25	3,339.33
34	100	93,930	83,490	95,936	115	12,911.67	8,285.09	64	1,436.61	3,189.97
35	96	95,360	83,380	97,686	117	13,075.09	8,409.94	64	1,514.10	3,151.05
36	81	84,490	72,850	83,072	114	11,209.42	7,187.99	64	1,245.64	2,775.79
37	77	90,700	77,770	89,050	115	11,679.17	7,707.85	66	1,363.82	2,607.50
38	67	80,610	66,230	78,218	118	10,757.02	6,746.53	63	1,207.68	2,802.81
39	60	83,050	70,750	81,536	115	11,091.82	7,068.26	64	1,304.08	2,719.48
40	55	75,140	61,560	72,644	118	9,553.46	6,298.63	66	1,119.96	2,134.87
41	44	66,890	55,890	62,753	112	8,857.41	5,455.05	62	976.20	2,426.16
42	37	54,680	43,990	49,713	113	6,919.25	4,330.24	63	777.45	1,811.56
43	37	59,400	50,040	54,016	108	7,517.76	4,695.08	62	797.02	2,025.66
44	28	44,090	37,520	40,148	107	5,679.85	3,532.00	62	657.81	1,490.04
45	36	63,670	50,130	59,614	119	8,352.88	5,172.29	62	892.09	2,288.50
46	20	32,450	28,410	29,705	105	4,149.03	2,590.20	62	485.39	1,073.44
47	22	40,370	32,820	37,650	115	5,344.32	3,288.47	62	616.30	1,439.55
48	20	40,240	35,010	37,477	107	5,274.39	3,267.47	62	537.77	1,469.15
49	13	26,850	23,750	25,955	109	3,521.97	2,259.41	64	356.33	906.23
50	14	26,450	21,520	23,386	109	3,342.29	2,060.76	62	381.76	899.77
51	8	17,520	14,380	17,087	119	2,288.41	1,460.26	64	238.29	589.86
52	9	18,450	14,530	16,033	110	2,366.50	1,401.75	59	254.75	710.00
53	5	11,570	7,580	10,379	137	1,611.93	898.57	56	157.41	555.95
54	8	18,010	14,150	14,736	104	2,301.66	1,284.02	56	212.95	804.69
55	4	12,430	11,350	11,650	103	1,628.03	1,003.09	62	137.65	487.29
56	4	9,560	6,550	7,825	120	1,280.02	667.95	52	123.05	489.02
57	2	4,570	4,020	4,445	111	593.07	381.29	64	53.37	158.41
58	1	3,150	1,760	2,179	124	373.32	185.25	50	21.29	166.78
59	3	9,150	7,480	8,750	117	1,147.87	754.85	66	122.57	270.45
60	--	--	--	--	--	--	--	--	--	--
61	--	--	--	--	--	--	--	--	--	--
62	1	3,620	2,940	3,486	119	432.99	291.87	67	38.41	102.71
63	--	--	--	--	--	--	--	--	--	--
64	2	7,740	6,890	7,245	105	1,011.13	621.84	61	95.82	293.47
65	1	3,190	2,800	2,672	95	434.62	228.55	53	31.33	174.74
66	--	--	--	--	--	--	--	--	--	--
67	--	--	--	--	--	--	--	--	--	--
68	1	4,370	3,480	3,526	101	623.85	293.12	47	40.50	290.93
Total or average	4,974	2,646,160	2,303,590	2,699,546	117	362,638.12	230,863.26	64	40,148.14	91,626.72

[1] As scaled by Bureau of Land Management scaler, east side log scaling rules, Scribner Decimal C log scale.

[2] Lumber tally volume as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Table 9—Lumber grade yields by scaling diameter, log grade No. 1

Log scaling diameter (inches)	Number of logs	Lumber tally volume	Lumber grade												
			B & Btr. Select	C Select	D Select	Mould-ing	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Select Struc-tural[1/]	Construc-tion	Std.	Util.	Econ.
		Bd. ft.	Percent of lumber tally volume												
8	1	29	0	0	0	0	0	0	0	0	82.76	0	0	17.24	0
9	1	35	0	0	0	0	0	0	0	0	0	100.00	0	0	0
10	5	401	0	0	0	0	0	0	1.00	0	37.91	45.64	14.71	.75	0
11	7	709	0	1.13	4.65	.71	1.83	0	0	0	38.93	39.92	8.32	.71	3.81
12	5	599	1.00	3.01	1.00	2.17	0	0	0	0	39.57	42.74	7.68	0	2.84
13	9	1,236	0	0	.16	0	0	0	0	0	53.07	40.29	5.02	1.21	.24
14	8	1,161	.26	2.84	4.13	1.72	0	0	0	2.15	52.71	21.45	4.13	10.34	.26
15	12	2,431	.21	3.54	3.41	.62	0	0	0	0	38.42	36.82	6.42	9.46	1.11
16	9	2,096	1.72	4.91	.86	.19	0	0	0	0	51.00	27.67	6.58	3.20	3.86
17	12	2,873	.56	6.54	3.48	0	0	0	0	0	51.06	24.92	5.78	6.61	1.04
18	9	2,256	.66	2.62	.75	1.33	0	.58	0	.75	51.37	22.78	9.13	9.62	.40
19	10	2,758	3.88	7.00	5.04	4.31	0	0	.40	0	51.12	16.10	6.24	4.75	1.16
20	12	3,774	1.19	4.77	6.25	5.19	.85	1.01	1.27	.50	31.64	27.45	11.05	7.31	1.51
21	17	6,814	3.45	10.01	2.19	.85	0	.23	.40	0	50.65	15.04	10.41	4.65	2.13
22	9	4,126	6.08	15.12	6.64	5.19	.80	.10	0	.41	44.52	10.49	7.30	2.57	.78
23	17	7,250	7.53	15.79	3.43	3.52	0	.17	1.06	0	33.27	16.40	9.06	6.23	3.53
24	10	4,748	1.92	14.13	10.47	6.30	0	.63	1.01	0	33.78	17.29	8.61	4.95	.91
25	13	7,182	12.18	18.10	2.80	.29	.47	.28	.70	.84	31.24	19.84	7.10	4.22	1.94
26	19	10,323	12.23	13.88	5.80	2.43	1.84	1.36	1.46	1.08	26.21	19.91	6.12	4.82	2.85
27	14	7,769	11.25	12.58	4.74	5.84	2.79	1.26	2.57	.28	19.40	16.78	9.58	9.58	3.35
28	14	10,273	8.08	15.21	3.05	4.37	.73	1.66	1.45	.64	36.11	16.66	6.68	4.66	.69
29	18	12,127	7.36	14.10	8.18	3.99	3.48	1.34	4.46	.49	15.99	18.59	11.80	6.12	4.10
30	19	14,072	10.41	9.69	4.30	1.33	5.74	6.06	4.37	.43	25.55	16.94	5.33	7.34	2.50
31	11	9,754	20.72	17.71	3.63	1.76	2.99	1.25	1.07	.12	29.21	9.93	5.68	3.53	2.40
32	20	15,098	11.27	15.16	4.46	3.12	4.29	3.83	6.40	1.05	19.75	16.19	3.93	7.84	2.71
33	18	16,420	19.24	10.86	5.29	4.76	4.35	3.45	3.64	1.65	12.06	15.23	8.28	6.61	4.56
34	13	10,608	22.95	13.41	2.71	3.44	7.31	4.32	2.42	.59	15.39	13.68	5.46	6.43	1.89
35	21	20,550	17.34	14.23	4.33	6.14	4.73	3.06	3.18	.34	19.08	11.07	6.57	7.09	2.85
36	19	18,579	17.90	14.17	3.68	3.80	2.68	5.48	7.17	1.91	16.57	13.42	5.40	5.54	2.28
37	19	20,957	25.90	15.05	7.07	1.75	3.96	4.87	3.14	2.14	10.60	12.74	4.79	5.45	2.55
38	20	24,261	20.58	17.48	6.89	1.84	2.49	2.64	2.88	.50	11.48	15.48	6.50	7.44	3.80
39	16	19,033	23.15	17.19	4.90	3.16	4.84	3.52	2.95	.37	12.18	11.58	5.04	7.92	3.18
40	17	20,225	21.80	20.06	6.31	6.96	3.04	2.89	3.99	1.49	9.87	10.55	4.43	5.62	2.98
41	16	19,870	22.78	18.57	5.01	5.74	4.80	3.76	3.60	.51	13.15	8.59	4.28	7.43	1.77
42	11	14,850	17.20	17.16	12.22	7.56	.54	.45	1.35	.32	10.11	15.25	5.58	8.13	4.14
43	15	23,875	33.55	19.18	7.72	3.37	3.33	2.18	3.34	.79	8.56	6.72	5.60	3.76	1.89
44	12	18,609	29.52	18.62	7.00	7.27	3.18	2.90	2.56	.92	9.25	9.02	3.83	4.25	1.69
45	9	14,589	30.76	20.58	5.71	6.52	1.61	1.90	2.73	1.12	7.26	7.62	4.26	5.44	4.49
46	8	11,646	32.13	14.16	3.51	4.43	5.64	6.72	6.09	.48	11.15	5.55	3.86	4.67	1.60
47	10	17,208	39.47	15.17	3.91	7.51	3.59	3.86	3.07	.31	8.00	7.22	2.99	2.88	2.02
48	13	23,774	28.17	20.62	5.10	5.50	2.99	3.92	4.50	.56	9.38	6.62	3.78	5.65	3.19
49	7	14,897	34.46	21.61	4.71	.24	2.12	2.74	4.14	.67	11.75	7.26	3.11	4.66	2.54
50	3	4,667	38.44	12.11	1.39	0	11.96	8.51	6.51	0	5.31	4.84	3.30	6.62	1.01
51	4	9,254	36.14	24.12	2.12	.04	4.26	3.78	2.78	.13	8.80	6.19	4.32	5.85	1.48
52	7	12,254	36.40	19.06	6.15	5.23	2.27	1.27	3.84	.69	4.28	7.39	4.39	5.70	3.32
53	2	3,550	24.37	13.49	4.56	13.86	6.62	5.18	5.35	.11	3.61	3.04	2.34	15.21	2.25
54	5	10,520	38.12	20.19	5.57	3.45	4.64	3.98	2.23	.47	7.26	6.83	1.61	3.68	1.98
55	4	11,650	53.12	23.16	2.32	0	2.70	1.27	.37	0	5.76	3.09	.87	6.03	1.32
56	1	1,836	72.88	17.10	0	0	.38	0	.60	0	3.43	1.74	1.58	1.91	.38
57	2	4,445	61.12	17.59	2.11	0	5.78	.88	1.24	.79	5.69	2.00	.40	2.11	.27
58	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
59	2	5,526	30.44	12.69	1.01	0	12.54	11.27	4.11	.47	7.82	4.25	2.77	7.51	5.12
60	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
61	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
62	1	3,486	40.91	14.37	2.95	1.95	0	0	0	0	.46	10.47	8.49	9.04	11.36
63	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
64	1	3,602	61.10	17.13	2.75	1.44	0	0	0	0	1.72	1.75	2.75	6.33	5.02
65	1	2,672	43.04	25.94	8.31	0	5.35	1.50	1.38	2.62	3.48	1.38	.94	3.85	2.21
66	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
67	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
68	1	3,526	44.07	28.16	3.91	1.64	0	0	0	0	2.21	2.67	4.03	5.30	8.00
Total or average	559	516,833	23.83	16.36	5.14	3.84	3.29	2.93	3.08	.70	15.42	11.59	5.25	5.87	2.70

[1/] Includes 1-inch Select Merchantable lumber.

Table 10—Lumber grade yields by scaling diameter, log grade No. 2

Log scaling diameter (inches)	Number of logs	Lumber tally volume	Lumber grade												
			B & Btr. Select	C Select	D Select	Mould-ing	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Select Struc-tural[1]	Construc-tion	Std.	Util.	Econ.
		Bd. ft.	Percent of lumber tally volume												
8	4	113	0	0	0	0	0	0	0	0	20.35	46.02	23.01	7.96	2.65
9	9	628	0	2.07	0	0	0	0	2.07	0	16.72	39.49	28.50	10.35	.80
10	14	1,227	.98	.33	.41	.41	0	0	0	0	34.56	37.73	16.14	5.30	4.16
11	15	1,344	0	.89	1.26	0	0	0	0	0	31.70	42.11	11.76	10.49	1.79
12	21	2,515	.16	1.71	1.99	.48	0	.12	0	0	39.36	36.82	13.52	4.85	.99
13	22	2,867	0	1.57	2.96	.56	0	0	0	0	24.14	42.20	18.84	7.15	2.58
14	27	4,209	.10	1.45	.40	.95	0	0	0	.40	32.81	33.67	13.52	11.26	5.44
15	17	2,939	0	1.70	1.94	.88	0	.58	0	1.36	36.00	31.98	12.11	6.26	7.18
16	24	4,918	.67	2.20	2.54	1.28	0	0	.35	.81	34.95	37.43	12.57	4.58	2.62
17	25	6,249	.21	1.52	.98	.80	.11	.26	1.17	.72	38.23	36.21	9.28	8.02	2.50
18	29	8,067	.25	3.17	3.17	1.95	0	.06	1.10	.94	37.14	32.59	10.26	7.19	2.17
19	30	8,840	.40	2.14	2.25	3.05	.23	.19	1.38	.70	36.78	31.89	10.42	8.11	2.47
20	33	11,339	.84	4.65	3.16	1.62	.07	.61	2.10	.36	36.16	28.34	12.66	6.91	2.52
21	41	14,578	1.78	4.97	4.81	4.09	.16	1.44	2.79	.86	29.41	32.63	7.58	8.09	1.39
22	39	15,516	.43	3.57	3.04	2.12	.03	.18	2.15	.43	34.20	31.66	11.68	7.86	2.66
23	40	18,176	2.78	6.12	4.98	1.47	.24	.40	1.60	.28	33.29	27.17	10.12	8.42	3.14
24	35	18,285	5.27	7.48	5.82	3.23	.43	.48	.62	.55	32.02	28.56	8.25	5.46	1.82
25	41	22,857	3.66	6.57	5.61	2.15	.35	2.04	3.25	.60	22.87	32.21	10.12	6.65	3.92
26	38	21,778	3.52	6.37	4.27	5.48	.73	.85	1.32	.62	25.64	29.25	12.47	7.37	2.10
27	38	24,854	5.62	9.71	5.25	2.04	1.19	2.20	2.03	.49	24.58	26.39	8.96	9.47	2.06
28	42	25,979	4.95	7.87	4.03	3.81	2.11	2.85	3.14	.65	19.06	25.40	10.64	9.45	6.03
29	41	30,603	5.12	9.71	3.77	2.55	2.59	5.22	3.23	.44	20.59	27.14	10.40	7.24	1.99
30	31	22,244	5.08	9.99	5.01	8.48	2.88	3.83	5.61	.48	13.70	21.79	10.64	8.80	3.71
31	45	34,325	5.84	7.01	4.62	5.53	3.87	5.75	6.42	.81	15.94	21.54	10.50	7.84	4.34
32	34	27,321	6.86	11.95	5.27	2.86	2.71	2.90	5.56	1.39	20.22	21.88	8.69	6.36	3.36
33	38	32,690	11.67	10.84	7.57	4.30	2.48	2.20	3.50	1.15	15.26	17.36	7.98	11.76	3.94
34	34	32,594	12.78	13.55	4.63	5.97	2.27	3.98	4.36	.47	15.57	16.75	7.97	7.96	3.73
35	40	39,714	10.12	14.62	6.47	4.45	2.42	2.81	5.55	1.21	14.63	17.08	7.18	10.04	3.42
36	22	28,846	12.58	11.50	4.58	4.93	2.01	5.47	6.59	.73	11.80	18.37	6.99	10.70	3.75
37	27	29,099	7.13	8.93	5.69	5.80	3.41	4.19	5.80	1.82	14.25	19.86	10.04	8.54	4.53
38	20	22,226	15.49	12.06	6.92	3.62	3.24	4.49	4.07	.72	11.03	14.35	10.86	9.64	3.50
39	18	26,765	16.37	19.34	5.79	6.63	1.91	2.21	1.94	.61	13.20	15.11	6.47	6.80	3.61
40	17	27,105	23.12	10.46	6.93	4.08	1.95	2.91	3.42	.26	12.46	11.66	7.34	13.15	2.26
41	13	18,625	9.42	18.90	7.84	8.37	2.41	3.00	2.06	.94	9.79	16.16	8.32	8.27	4.53
42	11	13,877	15.28	14.84	3.44	5.71	4.47	6.24	10.45	2.14	9.48	11.04	7.06	6.39	3.45
43	13	17,489	10.03	10.30	5.08	6.46	5.27	7.26	10.23	2.22	8.86	11.96	8.94	10.80	2.58
44	9	10,915	11.74	20.55	6.79	5.69	3.79	4.31	4.34	.60	3.80	6.85	8.21	17.98	5.35
45	12	20,520	13.33	11.37	6.22	.46	4.92	2.32	2.70	.96	9.16	19.34	14.00	12.98	2.24
46	6	9,040	9.82	9.83	4.21	9.42	9.16	8.01	6.47	3.89	4.90	12.48	6.25	9.99	5.55
47	6	10,940	16.89	14.17	8.98	13.41	1.83	3.98	5.57	2.86	7.81	7.18	6.50	8.15	2.69
48	6	10,547	12.48	15.83	9.32	.13	2.08	2.22	3.20	.25	10.60	17.44	10.49	12.98	3.00
49	5	9,302	16.28	16.04	2.80	.24	9.56	5.96	8.73	.85	7.46	8.19	7.98	9.25	6.69
50	8	14,269	18.43	14.77	5.61	9.94	5.40	9.32	8.00	.84	7.82	6.49	4.36	5.48	3.55
51	1	1,912	39.23	24.22	1.15	0	8.89	.47	0	0	5.65	11.14	2.93	2.93	3.40
52	1	1,377	32.97	15.32	1.45	0	6.39	11.62	13.58	3.41	0	4.94	1.74	5.30	3.27
53	1	1,879	32.57	24.32	2.24	0	6.28	3.30	3.73	0	3.57	7.08	3.99	10.64	2.29
54	2	2,616	27.41	28.63	2.71	0	12.92	1.64	.88	1.64	4.51	8.26	2.37	7.91	1.11
55	—	--	--	--	--	—	—	--	--	--	--	--	--	--	--	--
56	—	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
57	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
58	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
59	1	3,224	18.11	17.56	5.61	1.89	0	0	0	0	0	15.60	8.59	21.65	10.98
60	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
61	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
62	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
63	--	--	--	--	--	--	--	—	--	--	--	--	--	--	--	--
64	1	3,643	32.75	15.07	.66	0	10.49	6.26	4.28	.25	5.98	3.49	3.84	13.23	3.71
Total or average	1,047	712,985	9.23	10.59	5.19	4.30	2.51	3.22	4.03	.89	17.79	20.73	9.17	8.93	3.43

[1] Includes 1-inch Select Merchantable lumber.

Table 11—Lumber grade yields by scaling diameter, log grade No. 3

Log scaling diameter (inches)	Number of logs	Lumber tally volume	Lumber grade												
			B & Btr. Select	C Select	D Select	Mould-ing	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Select Struc-tural[1]	Construc-tion	Std.	Util.	Econ.
		Bd. ft.	Percent of lumber tally volume												
6	42	1,351	0.89	1.78	0.59	0	0	0	0	0	8.29	55.81	16.73	12.58	3.33
7	34	1,324	0	.60	0	0	0	0	0	0	6.65	46.90	27.49	11.78	6.57
8	86	4,228	.33	.57	.54	.43	.12	0	0	0	9.46	53.64	22.19	10.41	2.32
9	91	5,555	.41	.83	.18	.11	0	.31	.45	.22	12.44	47.31	24.70	10.93	2.12
10	103	7,940	.10	.76	.48	.21	0	0	.14	.14	11.94	47.61	21.74	14.27	2.62
11	100	9,902	.66	.78	.37	.13	.12	0	.12	0	13.03	50.39	23.14	8.98	2.28
12	105	11,886	.48	.21	.51	.28	0	.24	.14	.20	16.33	48.12	20.76	10.33	2.39
13	100	13,915	.04	.63	.72	.51	0	.05	.12	0	16.91	47.78	20.95	9.03	3.26
14	98	15,994	.11	.66	.48	.92	.09	0	.08	.58	12.15	47.88	23.38	11.24	2.45
15	87	15,821	.23	.37	.63	.58	0	.07	.25	.37	14.95	44.68	23.81	10.73	3.33
16	108	24,901	.18	.36	1.11	.31	.08	.15	.31	.44	14.74	44.63	23.87	11.26	2.57
17	75	19,231	.22	.86	.80	.98	0	.34	1.13	.47	18.98	41.39	22.01	10.61	2.22
18	103	29,629	.09	.75	.69	.28	0	.20	1.30	.44	16.18	44.84	20.26	12.21	2.75
19	84	26,532	.28	1.16	1.11	1.13	.05	.27	1.24	.82	16.61	43.19	20.92	10.64	2.57
20	95	34,326	.45	.86	.84	.71	.13	.65	1.93	.80	16.61	40.31	22.53	11.26	2.92
21	66	27,079	.75	2.01	1.73	.99	.09	.54	1.99	.43	12.25	40.67	22.63	12.32	3.60
22	73	32,399	.46	1.59	1.30	1.01	.15	.49	3.01	.50	15.33	40.10	21.32	11.66	3.07
23	74	35,377	1.06	1.47	1.71	.86	.13	1.14	3.23	.29	14.93	37.27	20.76	14.24	2.91
24	71	37,744	1.47	2.23	1.62	1.49	.25	1.56	4.11	.81	18.05	39.06	17.94	8.77	2.63
25	65	37,919	1.07	2.30	2.30	.92	.64	1.06	3.25	.54	13.18	39.48	17.91	12.94	4.40
26	61	38,026	1.72	3.35	2.93	1.87	.28	1.68	5.14	.65	14.46	32.20	18.16	14.83	2.72
27	51	34,867	2.11	4.06	2.30	2.02	.70	2.82	4.72	1.11	11.58	30.77	21.49	11.15	5.17
28	47	31,725	2.42	5.17	3.14	1.99	1.26	2.82	3.82	.35	12.40	30.33	18.22	13.91	4.17
29	47	35,106	2.28	5.18	3.09	2.26	1.22	3.16	4.39	1.74	13.75	28.62	16.01	13.45	4.85
30	38	30,881	2.47	5.28	3.83	3.96	1.02	3.56	5.97	.84	10.97	25.11	17.17	14.38	5.44
31	34	29,923	3.75	7.62	4.39	2.13	.76	3.94	7.10	1.16	9.67	30.91	14.87	10.62	3.06
32	34	32,853	3.77	5.11	3.02	1.90	1.07	3.91	4.76	.90	10.98	26.41	17.61	15.66	4.92
33	35	32,184	2.99	6.49	4.11	3.15	.64	3.13	6.84	1.06	9.85	23.69	17.15	15.48	5.43
34	34	35,260	7.05	6.80	3.59	2.19	1.69	1.97	4.52	.71	6.83	23.10	21.53	16.63	3.40
35	20	21,664	4.24	5.95	5.26	1.07	.45	3.08	2.92	.90	8.93	23.42	16.56	22.74	4.50
36	24	24,926	1.81	3.59	3.80	4.83	2.42	6.70	7.32	2.04	5.73	19.89	16.36	18.82	6.68
37	23	29,346	5.23	8.58	4.69	4.57	2.59	6.44	4.89	.81	5.28	28.15	14.45	10.67	3.65
38	16	20,290	4.26	9.88	4.85	2.45	1.15	4.71	4.39	.60	4.22	20.51	17.82	17.08	8.07
39	15	20,831	1.30	5.12	3.01	4.11	1.71	4.54	4.76	.33	5.57	22.83	16.35	21.22	9.16
40	13	16,660	1.96	4.57	4.10	6.39	1.45	5.96	10.28	2.70	5.59	13.04	17.33	16.35	10.28
41	10	15,814	6.93	10.64	5.44	3.97	1.23	5.34	3.90	1.15	2.52	17.49	20.70	17.25	3.43
42	10	14,916	5.77	12.06	6.22	3.33	1.01	3.47	5.52	.48	11.30	16.53	8.66	16.32	9.33
43	4	4,769	2.33	19.63	5.47	0	.69	4.86	5.83	2.14	.71	1.93	9.98	35.21	11.22
44	6	9,702	4.12	16.32	5.66	6.85	1.18	5.45	10.80	1.59	5.28	13.74	13.07	11.81	4.13
45	8	14,444	5.70	12.68	5.83	4.02	2.71	5.36	5.86	1.28	5.18	13.11	11.50	23.43	3.36
46	3	4,490	4.32	14.90	7.88	17.39	1.11	4.43	11.92	1.11	3.23	6.77	6.26	12.23	8.44
47	5	8,289	1.31	6.27	7.18	4.55	.48	5.53	2.64	1.24	.70	7.65	13.78	35.94	12.73
48	1	3,156	8.68	21.89	17.30	0	0	0	0	0	3.17	11.31	19.93	13.97	3.74
49	1	1,756	12.19	20.16	18.05	23.35	0	1.31	2.33	0	7.80	3.47	2.51	4.04	4.78
50	2	3,017	2.55	12.86	4.31	.30	.36	1.39	2.19	3.45	1.59	7.89	9.21	32.62	21.28
51	3	5,921	4.59	7.99	4.53	.07	0	0	0	.20	1.76	12.60	12.23	42.10	13.93
52	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
53	1	2,587	6.84	14.15	6.73	0	0	0	0	0	0	16.08	5.88	37.73	12.60
54	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
56	3	5,992	.95	12.83	5.21	0	5.76	.63	4.49	.13	1.75	11.48	11.63	34.88	10.25
57	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
58	1	2,179	2.16	7.99	.78	.37	0	0	0	0	2.39	13.95	7.34	29.42	35.61
tal or verage	2,210	924,627	2.26	4.53	2.88	2.09	.76	2.37	3.80	.79	11.41	31.63	18.55	14.40	4.52

[1] Includes 1-inch Select Merchantable lumber.

Table 12—Lumber grade yields by scaling diameter, log grade No. 4

Log scaling diameter (inches)	Number of logs	Lumber tally volume	Lumber grade												
			B & Btr. Select	C Select	D Select	Mould-ing	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Select Struc-tural[1]	Construc-tion	Std.	Util.	Econ.
		Bd. ft.	Percent of lumber tally volume												
6	6	254	0	0	0	0	0	0	0	0	0	51.97	20.47	20.47	7.09
7	1	82	0	0	0	0	0	0	0	0	0	40.24	41.46	4.88	13.41
8	14	861	0	0	0	0	0	0	0	0	7.55	36.93	30.08	19.51	5.92
9	22	1,901	0	0	0	0	0	0	0	0	2.31	29.77	42.87	18.62	6.42
10	22	1,694	0	.18	0	.41	0	0	0	0	1.24	29.75	31.35	26.33	10.74
11	30	3,205	0	1.34	0	0	0	0	0	0	.31	28.17	33.48	28.14	8.55
12	37	4,348	0	.69	.32	.76	0	0	0	.28	3.36	26.43	33.92	28.13	6.12
13	40	6,184	.16	.24	.19	.10	0	.15	0	.24	2.81	34.15	32.63	22.36	6.95
14	49	8,458	.05	.31	.46	.38	0	0	0	.09	5.04	27.02	34.31	21.81	10.53
15	51	9,688	.37	.56	.18	0	0	.09	0	0	2.36	37.52	30.70	22.00	6.22
16	53	12,372	.08	.27	.12	0	0	.13	.95	.36	4.00	24.93	35.23	26.33	7.60
17	49	12,296	0	.38	.54	.15	.11	0	.16	.16	4.03	22.58	31.08	30.80	10.00
18	53	14,467	.63	.62	.19	.44	0	0	.91	.59	4.35	28.12	28.94	27.39	7.81
19	52	16,309	.18	.49	.75	.20	.03	.02	1.23	.37	1.96	23.50	34.51	26.70	10.06
20	66	22,910	.16	1.01	.60	.85	0	.38	2.50	1.65	4.74	25.17	27.54	26.83	8.56
21	45	17,009	.22	.94	.73	.26	.31	.04	2.25	.58	4.93	26.18	22.61	31.83	9.12
22	53	21,202	.42	.28	.51	.45	.09	.32	3.11	1.41	5.49	25.69	22.65	29.32	10.25
23	43	20,086	.30	.79	1.15	.85	.03	.37	4.61	1.63	4.32	20.10	29.12	25.67	11.06
24	44	21,541	.37	.98	1.34	1.20	.66	.96	4.61	1.50	3.56	23.86	25.21	28.03	7.73
25	48	23,587	.27	1.31	.94	1.02	.08	1.63	4.29	1.59	3.20	27.07	25.77	23.67	9.18
26	43	24,385	.32	.96	1.41	.90	.11	.81	4.65	2.18	3.05	20.98	29.49	25.39	9.74
27	43	25,426	.54	1.91	.94	1.87	.49	2.59	8.08	2.12	4.24	20.04	19.62	30.21	7.37
28	39	26,260	.61	1.99	1.07	.98	1.81	2.76	6.54	.87	3.87	23.50	22.88	23.11	10.00
29	31	21,951	1.33	1.94	1.37	1.47	.95	4.06	10.33	1.92	4.48	18.01	21.06	22.02	11.07
30	23	16,263	.53	2.57	1.58	1.69	.70	2.95	5.42	1.56	3.41	17.28	23.72	26.00	12.59
31	29	24,978	1.78	3.47	2.43	1.44	.68	3.23	8.20	.92	2.74	13.88	25.83	25.78	9.63
32	33	26,688	1.16	2.14	1.46	1.18	1.49	3.09	8.91	1.47	3.02	15.70	20.54	28.86	10.97
33	20	17,173	1.56	2.83	2.18	2.77	1.05	6.21	8.88	1.95	3.72	18.60	20.29	19.65	10.31
34	19	17,474	.88	2.33	1.64	1.64	2.33	6.49	13.23	3.00	3.62	10.87	18.99	27.21	7.78
35	15	15,758	1.03	2.44	3.45	2.46	.65	2.61	4.58	.52	1.18	23.22	21.69	26.55	9.61
36	16	18,721	.86	4.07	2.89	2.20	2.08	2.99	8.50	1.98	1.63	20.07	15.46	23.89	13.38
37	8	9,648	1.13	9.14	2.21	.12	.83	1.83	4.46	.55	1.41	11.89	18.67	33.54	14.22
38	11	11,441	1.67	5.70	2.10	3.66	2.48	5.14	6.84	1.46	4.22	11.91	14.61	29.28	10.93
39	11	14,907	.62	4.65	2.58	4.14	2.15	4.07	7.88	1.99	.82	9.73	8.26	38.94	14.17
40	8	8,654	.99	3.95	3.17	.08	.32	4.34	5.81	1.12	1.31	20.04	17.56	35.78	5.52
41	5	8,444	2.90	4.43	4.01	1.16	1.79	4.62	6.08	1.31	2.31	11.43	12.28	29.81	17.87
42	5	6,070	3.64	6.23	2.41	0	0	2.75	5.44	1.33	2.97	16.51	18.39	29.32	11.02
43	5	7,883	1.33	6.29	2.26	3.39	5.63	7.43	8.75	3.07	2.21	8.26	13.93	29.77	7.67
44	1	922	5.75	1.41	2.60	19.31	2.06	6.94	23.54	4.34	0	22.99	7.81	3.25	0
45	7	10,061	1.90	4.04	2.48	.87	3.69	2.94	9.85	3.30	.57	12.53	7.12	31.70	19.01
46	3	4,529	0	.62	0	2.72	0	.62	2.45	5.65	1.26	7.64	24.57	35.02	19.45
47	1	1,213	4.45	2.72	7.01	0	.66	4.04	2.23	3.13	0	.49	4.29	55.73	15.25
48	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
49	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
50	1	1,433	0	.28	.63	10.40	0	18.49	44.52	10.68	0	0	1.12	7.47	6.42
51	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
52	1	2,402	0	3.79	2.87	0	0	0	0	0	0	0	4.75	74.52	14.07
53	1	2,363	4.23	4.15	.80	.34	0	0	0	0	.68	1.82	8.84	37.96	41.18
54	1	1,600	.81	0	2.06	33.31	0	14.25	16.75	3.31	0	6.19	5.25	13.25	4.81
Total or average	1,158	545,101	.78	2.13	1.44	1.37	.84	2.28	5.56	1.44	3.25	20.22	23.12	27.33	10.24

[1] Includes 1-inch Select Merchantable lumber.

Table 13—Lumber grade yields by scaling diameter for all log grades

Log scaling diameter (inches)	Number of logs	Lumber tally volume	Lumber grade								Select Structural[1]	Construction	Std.	Util.	Econ.
			B & Btr. Select	C Select	D Select	Mould-ing	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop					
		Bd. ft.	Percent of lumber tally volume												
6	48	1,605	0.75	1.50	0.50	0	0	0	0	0	6.98	55.20	17.32	13.83	3.93
7	35	1,406	0	.57	0	0	0	0	0	0	6.26	46.51	28.31	11.38	6.97
8	105	5,231	.27	.46	.44	.34	.10	0	0	0	9.79	50.43	23.38	11.89	2.91
9	123	8,119	.28	.73	.12	.07	0	.21	.47	.15	10.35	42.83	29.14	12.64	3.02
10	144	11,262	.18	.59	.38	.26	0	0	.13	.10	13.72	43.78	22.32	14.62	3.92
11	152	15,160	.43	.92	.57	.12	.16	0	.08	0	13.21	44.47	23.62	12.78	3.63
12	168	19,348	.35	.60	.68	.47	0	.16	.09	.19	17.13	41.61	22.37	13.30	3.06
13	171	24,202	.07	.61	.82	.38	0	.07	.07	.06	16.01	43.26	22.87	11.82	3.97
14	182	29,822	.09	.75	.60	.80	.05	0	.04	.48	14.63	38.93	24.34	14.20	5.08
15	167	30,879	.25	.80	.83	.43	0	.12	.13	.32	14.85	40.61	23.49	13.74	4.43
16	194	44,287	.28	.76	.98	.32	.04	.12	.48	.44	15.70	37.52	24.97	14.35	4.04
17	161	40,649	.17	1.22	.94	.63	.05	.20	.76	.38	19.68	33.74	21.65	16.04	4.53
18	194	54,149	.28	1.15	.93	.61	0	.14	1.11	.57	17.60	37.67	20.63	15.40	3.91
19	176	54,439	.45	1.41	1.39	1.33	.07	.17	1.22	.62	17.24	34.08	22.54	14.74	4.72
20	206	72,349	.46	1.70	1.41	1.13	.12	.58	2.10	.98	16.70	32.97	21.97	15.30	4.57
21	169	65,480	1.12	3.22	2.20	1.48	.15	.58	2.07	.52	18.16	32.45	18.00	15.65	4.39
22	174	73,243	.76	2.39	1.74	1.32	.14	.35	2.69	.74	18.13	32.47	18.88	15.46	4.93
23	174	80,889	1.84	3.63	2.46	1.24	.12	.70	3.01	.59	18.06	28.87	19.40	15.06	5.04
24	160	82,318	2.05	3.76	2.99	2.08	.38	1.11	3.29	.89	18.27	31.49	17.15	12.86	3.68
25	167	91,545	2.38	4.35	2.82	1.20	.41	1.39	3.32	.85	14.45	32.93	17.14	13.45	5.32
26	161	94,512	2.92	4.58	3.16	2.51	.51	1.23	3.73	1.08	15.37	27.29	18.46	14.74	4.40
27	146	92,916	3.38	5.70	2.92	2.30	.95	2.46	4.74	1.15	13.70	25.49	16.63	15.78	4.78
28	142	94,237	3.23	6.12	2.80	2.47	1.59	2.69	4.13	.61	14.44	25.58	16.17	14.24	5.93
29	137	99,787	3.56	6.94	3.54	2.39	1.86	3.77	5.35	1.23	14.08	24.61	14.89	12.54	5.25
30	111	83,460	4.13	6.75	3.79	4.28	2.25	3.93	5.50	.82	12.69	21.32	14.71	13.97	5.88
31	119	98,980	5.65	7.35	3.90	3.10	2.04	4.12	6.55	.88	12.02	21.30	15.21	12.78	5.10
32	121	101,960	5.03	7.65	3.43	2.15	2.10	3.41	6.30	1.20	12.67	20.88	13.96	15.46	5.76
33	111	98,467	8.33	8.03	5.12	3.73	1.94	3.41	5.55	1.34	10.94	19.29	13.17	13.49	5.64
34	100	95,936	9.63	9.01	3.49	3.51	2.63	3.73	5.82	1.03	10.16	17.67	14.68	14.48	4.14
35	96	97,686	8.87	10.65	5.26	3.73	2.18	2.89	4.31	.85	12.13	18.21	11.47	14.90	4.54
36	81	83,072	7.90	8.05	3.77	4.03	2.30	5.28	7.37	1.67	8.76	18.10	11.36	14.95	6.47
37	77	89,050	10.27	10.28	5.31	3.82	2.99	4.83	4.73	1.43	9.04	20.06	11.19	11.22	4.82
38	67	78,218	12.13	12.25	5.67	2.77	2.35	4.07	4.19	.73	8.41	15.94	11.86	13.76	5.87
39	60	81,536	11.22	12.52	4.29	4.72	2.59	3.45	3.98	.73	8.75	15.28	8.99	16.62	6.86
40	55	72,644	15.26	11.01	5.66	4.94	1.95	3.78	5.44	1.27	8.83	12.67	10.04	14.48	4.69
41	44	62,753	12.14	14.77	5.83	5.46	2.79	4.05	3.55	.91	8.02	13.46	10.69	13.17	5.17
42	37	49,713	11.58	13.65	6.77	4.85	1.71	3.25	5.64	1.00	9.42	14.61	8.48	12.69	6.34
43	37	54,016	18.48	14.46	5.87	4.08	4.06	4.83	6.58	1.71	7.04	8.22	8.29	12.61	3.78
44	28	40,148	18.00	18.19	6.52	7.01	2.83	3.99	5.52	1.07	6.60	9.89	7.35	9.79	3.24
45	36	59,614	13.82	12.70	5.37	2.88	3.36	3.06	4.68	1.47	6.28	13.81	9.85	16.82	5.89
46	20	29,705	16.24	10.89	3.85	7.65	5.17	5.84	6.53	2.40	6.54	8.16	8.11	12.06	6.56
47	22	37,650	23.38	12.52	6.20	8.33	2.30	4.27	3.67	1.35	6.08	7.09	6.43	13.39	5.00
48	20	37,477	22.11	19.38	7.31	3.52	2.48	3.11	3.76	.43	9.20	10.06	7.03	8.41	3.18
49	13	25,955	26.43	19.51	4.92	1.80	4.64	3.80	5.66	.69	9.95	7.34	4.81	6.26	4.18
50	14	23,386	19.25	13.11	4.29	6.74	5.73	8.70	9.19	1.61	6.04	5.94	4.58	9.33	5.50
51	8	17,087	25.55	18.54	2.84	.05	3.30	2.10	1.50	.14	6.00	8.97	6.91	18.08	6.01
52	9	16,033	30.65	16.45	5.26	4.00	2.28	1.97	4.10	.82	3.27	6.07	4.22	15.97	4.93
53	5	10,379	16.90	13.49	3.83	4.82	3.40	2.37	2.51	.04	2.03	6.74	5.00	25.18	13.70
54	8	14,736	32.17	19.50	4.68	6.08	5.61	4.68	3.57	.98	5.99	7.01	2.14	5.47	2.13
55	4	11,650	53.12	23.16	2.32	0	2.70	1.27	.37	0	5.76	3.09	.87	6.03	1.32
56	4	7,828	17.82	13.83	3.99	0	4.50	.49	3.58	.10	2.15	9.20	9.27	27.15	7.93
57	2	4,445	61.12	17.59	2.11	0	5.78	.88	1.24	.79	5.69	2.00	.40	2.11	.27
58	1	2,179	2.16	7.99	.78	.37	0	0	0	0	2.39	13.95	7.34	29.42	35.61
59	3	8,750	25.90	14.48	2.71	.70	7.92	7.12	2.59	.30	4.94	8.43	4.91	12.72	7.28
60	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
61	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
62	1	3,486	40.91	14.37	2.95	1.95	0	0	0	0	.46	10.47	8.49	9.04	11.36
63	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
64	2	7,245	46.85	16.09	1.70	.72	5.27	3.15	2.15	.12	3.86	2.62	3.30	9.80	4.36
65	1	2,672	43.04	25.94	8.31	0	5.35	1.50	1.38	2.62	3.48	1.38	.94	3.85	2.21
66	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
67	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
68	1	3,526	44.07	28.16	3.91	1.64	0	0	0	0	2.21	2.67	4.03	5.30	8.00
Total or average	4,974	2,699,546	7.93	7.91	3.63	2.87	1.72	2.68	4.08	.93	12.21	22.61	14.45	13.93	5.04

[1] Includes 1-inch Select Merchantable lumber.

Table 14—Cubic volumes by scaling diameter, log grade 1

(In cubic meters)

Scaling diameter		Logs	Lumber	Sawdust	Residue
Inches	Centimeters				
8	20.32	0.20	0.06	0.01	0.12
9	22.86	.17	.08	.01	.07
10	25.40	1.56	.95	.16	.43
11	27.94	2.86	1.67	.30	.88
12	30.48	2.10	1.43	.25	.41
13	33.02	5.16	2.95	.43	1.77
14	35.56	5.13	2.78	.43	1.90
15	38.10	9.47	5.80	.92	2.74
16	40.64	7.52	5.01	.74	1.77
17	43.18	12.00	6.87	1.04	4.09
18	45.72	8.60	5.41	.86	2.32
19	48.26	11.01	6.52	1.08	3.40
20	50.80	15.59	9.16	1.48	4.94
21	53.34	24.35	16.51	2.49	5.34
22	55.88	14.71	10.01	1.56	3.14
23	58.42	28.66	17.32	2.83	8.50
24	60.96	18.50	11.48	1.88	5.13
25	63.50	26.88	17.22	2.88	6.85
26	66.04	39.86	25.01	3.96	10.87
27	68.58	29.44	18.95	3.21	7.26
28	71.12	36.79	24.86	3.75	8.17
29	73.66	44.35	29.59	5.34	9.42
30	76.20	53.24	34.31	5.24	13.68
31	78.74	36.67	23.69	3.53	9.44
32	81.28	56.89	36.80	6.09	13.99
33	83.82	64.15	39.85	7.03	17.26
34	86.36	42.26	26.14	4.33	11.79
35	88.90	78.18	50.48	8.65	19.04
36	91.44	72.62	45.73	7.92	18.96
37	93.98	81.08	51.39	9.18	20.49
38	96.52	96.39	59.09	10.18	27.11
39	99.06	71.67	46.79	8.11	16.76
40	101.60	76.56	50.55	9.16	16.84
41	104.14	81.10	48.95	8.23	23.91
42	106.68	55.50	36.52	6.07	12.90
43	109.22	88.89	58.67	9.49	20.72
44	111.76	68.12	46.39	7.74	13.98
45	114.30	56.10	35.84	6.60	13.65
46	116.84	43.47	29.03	5.11	9.32
47	119.38	65.15	42.32	7.09	15.73
48	121.92	96.40	59.00	10.11	27.28
49	124.46	56.20	36.44	5.64	14.11
50	127.00	18.13	11.67	2.13	4.32
51	129.54	33.49	22.49	3.34	7.65
52	132.08	52.04	30.29	5.43	16.31
53	134.62	17.84	8.83	1.69	7.30
54	137.16	41.68	25.86	4.05	11.75
55	139.70	46.10	28.40	3.89	13.79
56	142.24	9.31	4.34	.70	4.26
57	144.78	16.79	10.80	1.51	4.48
58	147.32	--	--	--	--
59	149.86	21.20	13.69	2.47	5.02
60	152.40	--	--	--	--
61	154.94	--	--	--	--
62	157.48	12.26	8.26	1.08	2.90
63	160.02	--	--	--	--
64	162.56	13.46	8.53	1.21	3.71
65	165.10	12.31	6.47	.88	4.94
66	167.64	--	--	--	--
67	170.18	--	--	--	--
68	172.72	17.67	8.30	1.14	8.21
Total		1 997.84	1 265.56	210.83	521.43

Table 15—Cubic volumes by scaling diameter, log grade 2

(In cubic meters)

Scaling diameter		Logs	Lumber	Sawdust	Residue
Inches	Centimeters				
8	20.32	0.60	0.27	0.05	0.28
9	22.86	2.41	1.49	.26	.66
10	25.40	4.60	2.92	.47	1.21
11	27.94	6.10	3.18	.54	2.39
12	30.48	9.82	5.94	1.03	2.85
13	33.02	11.74	6.75	1.16	3.84
14	35.56	17.23	9.88	1.70	5.65
15	38.10	12.17	6.96	1.07	4.14
16	40.64	19.43	11.76	1.85	5.83
17	43.18	23.50	14.74	2.30	6.46
18	45.72	31.17	19.15	3.12	8.91
19	48.26	33.92	21.12	3.40	9.40
20	50.80	42.43	27.13	4.52	10.78
21	53.34	57.78	35.00	5.96	16.82
22	55.88	58.40	37.09	6.08	15.23
23	58.42	66.46	43.49	7.28	15.69
24	60.96	69.40	44.00	7.74	17.66
25	63.50	85.33	55.09	9.53	20.71
26	66.04	78.41	52.33	8.77	17.32
27	68.58	92.93	60.11	10.25	22.57
28	71.12	100.52	63.13	10.98	26.41
29	73.66	110.80	74.51	12.56	23.73
30	76.20	85.96	54.53	9.92	21.51
31	78.74	133.17	84.60	14.65	33.92
32	81.28	103.18	66.83	11.20	25.14
33	83.82	127.81	80.09	14.03	33.69
34	86.36	127.64	79.87	13.42	34.35
35	88.90	158.26	97.30	18.10	42.86
36	91.44	81.57	51.41	8.85	21.31
37	93.98	111.38	71.66	12.19	27.53
38	96.52	86.87	54.39	10.04	22.44
39	99.06	106.11	65.85	12.84	27.42
40	101.60	96.25	66.43	11.70	18.12
41	104.14	78.78	46.16	8.51	24.11
42	106.68	52.20	35.05	6.50	10.65
43	109.22	72.67	43.47	7.97	21.23
44	111.76	52.40	27.16	5.82	19.42
45	114.30	78.44	50.08	7.80	20.56
46	116.84	36.87	22.57	4.53	9.78
47	119.38	42.71	27.79	5.10	9.82
48	121.92	41.86	25.92	3.93	12.01
49	124.46	36.72	23.05	3.54	10.13
50	127.00	56.06	35.70	3.80	13.72
51	129.54	7.21	4.62	.63	1.96
52	132.08	5.96	3.52	.61	1.82
53	134.62	9.54	4.63	.69	4.22
54	137.16	16.02	6.37	.98	8.68
55	139.70	--	--	--	--
56	142.24	--	--	--	--
57	144.78	--	--	--	--
58	147.32	--	--	--	--
59	149.86	11.31	7.68	.99	2.63
60	152.40	--	--	--	--
61	154.94	--	--	--	--
62	157.48	--	--	--	--
63	160.02	--	--	--	--
64	162.56	15.17	9.08	1.49	4.59
Total		2 767.30	1 741.83	303.29	722.17

Table 16—Cubic volumes by scaling diameter, log grade 3

(In cubic meters)

Scaling diameter		Logs	Lumber	Sawdust	Residue
Inches	Centimeters				
6	15.24	7.51	3.22	0.62	3.67
7	17.78	6.87	3.14	.62	3.10
8	20.32	21.29	9.90	1.90	9.48
9	22.86	26.08	13.03	2.52	10.53
10	25.40	34.51	18.60	3.50	12.42
11	27.94	40.66	23.35	4.34	12.97
12	30.48	48.01	27.89	5.10	15.02
13	33.02	53.40	32.52	5.81	15.07
14	35.56	60.79	37.38	6.61	16.80
15	38.10	60.23	37.09	6.34	16.80
16	40.64	87.38	57.97	10.10	19.30
17	43.18	68.66	45.41	7.61	15.64
18	45.72	105.38	69.58	11.99	23.80
19	48.26	94.45	62.57	10.40	21.48
20	50.80	120.12	81.15	13.90	25.07
21	53.34	95.08	64.49	10.73	19.85
22	55.88	113.46	77.17	12.85	23.45
23	58.42	124.34	84.28	14.23	25.84
24	60.96	130.64	90.49	15.39	24.76
25	63.50	136.95	91.70	14.61	30.64
26	66.04	137.26	91.14	16.17	29.96
27	68.58	123.74	84.29	15.08	24.36
28	71.12	114.01	76.14	13.04	24.82
29	73.66	124.06	84.99	14.54	24.54
30	76.20	109.30	75.03	14.15	20.13
31	78.74	105.99	72.95	12.87	20.18
32	81.28	120.33	79.53	14.09	26.71
33	83.82	119.00	78.10	14.10	26.80
34	86.36	129.27	85.74	15.20	28.33
35	88.90	79.25	52.49	9.65	17.11
36	91.44	93.35	60.79	10.73	21.84
37	93.98	101.75	72.12	13.27	16.35
38	96.52	75.01	49.67	9.01	16.33
39	99.06	78.60	51.00	8.76	18.83
40	101.60	59.58	40.41	7.70	11.46
41	104.14	58.56	38.80	7.09	12.67
42	106.68	60.79	36.51	7.10	17.17
43	109.22	21.69	11.49	2.13	8.07
44	111.76	36.65	24.10	4.51	8.04
45	114.30	57.94	35.68	5.93	16.32
46	116.84	19.20	11.28	2.06	5.86
47	119.38	32.80	20.10	4.68	8.02
48	121.92	11.10	7.61	1.18	2.31
49	124.46	6.81	4.49	.91	1.42
50	127.00	13.77	7.14	1.10	5.54
51	129.54	24.10	14.24	2.77	7.08
52	132.08	--	--	--	--
53	134.62	9.70	6.29	1.43	1.97
54	137.16	--	--	--	--
55	139.70	--	--	--	--
56	142.24	26.94	14.58	2.78	9.58
57	144.78	--	--	--	--
58	147.32	10.57	5.25	.60	4.72
Total		3 396.92	2 222.89	391.81	782.22

Table 17—Cubic volumes by scaling diameter, log grade 4

(In cubic meters)

Scaling diameter		Logs	Lumber	Sawdust	Residue
Inches	Centimeters				
6	15.24	1.70	.61	.12	.98
7	17.78	.32	.20	.04	.08
8	20.32	3.82	2.03	.35	1.44
9	22.86	9.25	4.48	.81	3.96
10	25.40	8.77	3.91	.80	4.05
11	27.94	15.21	7.50	1.46	6.25
12	30.48	19.36	10.22	1.85	7.29
13	33.02	25.89	14.55	2.56	8.78
14	35.56	33.46	19.65	3.64	10.17
15	38.10	38.38	22.63	4.06	11.69
16	40.64	47.31	28.86	5.24	13.21
17	43.18	49.85	29.29	4.94	15.62
18	45.72	56.69	33.92	5.59	17.19
19	48.26	64.27	38.09	6.41	19.77
20	50.80	87.40	54.41	9.15	23.84
21	53.34	61.97	39.71	7.30	14.95
22	55.88	81.28	49.65	9.26	22.37
23	58.42	74.42	48.36	8.87	17.18
24	60.96	79.91	51.49	8.75	19.67
25	63.50	87.06	55.79	9.64	21.63
26	66.04	90.29	58.15	10.45	21.69
27	68.58	93.37	61.45	10.20	21.72
28	71.12	99.42	63.19	11.44	24.80
29	73.66	79.43	53.10	9.72	16.61
30	76.20	63.21	38.85	7.30	17.06
31	78.74	99.79	60.65	9.76	29.38
32	81.28	101.32	64.78	11.49	25.04
33	83.82	66.47	42.15	7.51	16.81
34	86.36	66.44	42.86	7.73	15.85
35	88.90	54.55	37.87	6.47	10.21
36	91.44	69.87	45.61	7.77	16.49
37	93.98	36.51	23.08	3.97	9.46
38	96.52	46.34	27.90	4.97	13.47
39	99.06	57.70	36.51	7.20	13.99
40	101.60	38.14	20.96	3.15	14.02
41	104.14	32.37	20.56	3.80	8.01
42	106.68	27.45	14.53	2.34	10.58
43	109.22	29.63	19.32	2.98	7.34
44	111.76	3.67	2.36	.56	.75
45	114.30	44.05	24.86	4.92	14.27
46	116.84	17.94	10.46	2.04	5.44
47	119.38	10.68	2.91	.58	7.19
48	121.92	—	--	--	—
49	124.46	—	--	—	--
50	127.00	6.69	3.85	.95	1.89
51	129.54	--	--	--	--
52	132.08	9.01	5.88	1.16	1.97
53	134.62	8.57	5.69	.63	2.24
54	137.16	7.48	4.13	1.00	2.35
Total		2 106.69	1 307.02	230.93	568.74

Table 18—Cubic volumes by scaling diameter for all grades

(In cubic meters)

Scaling diameter		Logs	Lumber	Sawdust	Residue
Inches	Centimeters				
6	15.24	9.21	3.83	0.74	4.65
7	17.78	7.19	3.34	.66	3.19
8	20.32	25.91	12.27	2.31	11.33
9	22.86	37.92	19.09	3.61	15.22
10	25.40	49.44	26.38	4.93	18.12
11	27.94	64.83	35.70	6.63	22.50
12	30.48	79.29	45.47	8.24	25.57
13	33.02	96.20	56.78	9.96	29.46
14	35.56	116.61	69.69	12.40	34.53
15	38.10	120.25	72.47	12.40	35.38
16	40.64	161.65	103.60	17.93	40.12
17	43.18	154.02	96.30	15.91	41.81
18	45.72	201.84	128.05	21.56	52.23
19	48.26	203.65	128.30	21.30	54.06
20	50.80	265.53	171.85	29.05	64.63
21	53.54	239.18	155.71	26.49	56.97
22	55.88	267.85	173.90	29.76	64.20
23	58.42	293.87	193.45	33.21	67.21
24	60.96	298.46	197.46	33.77	67.23
25	63.50	336.23	219.80	36.58	79.84
26	66.04	345.83	226.64	39.35	79.84
27	68.58	339.47	224.80	38.74	75.93
28	71.12	350.73	227.31	39.21	84.20
29	73.66	358.65	242.19	42.17	74.30
30	76.20	311.72	202.72	36.62	72.38
31	78.74	375.62	241.89	40.81	92.92
32	81.28	381.71	247.95	42.88	90.89
33	83.82	377.44	240.20	42.68	94.56
34	86.36	365.62	234.61	40.68	90.33
35	88.90	370.24	238.14	42.87	89.23
36	91.44	317.41	203.54	35.27	78.60
37	93.98	330.72	218.26	38.62	73.84
38	96.52	304.60	191.04	34.20	79.37
39	99.06	314.08	200.15	36.93	77.01
40	101.60	270.52	178.36	31.71	60.45
41	104.14	250.81	154.57	27.64	68.70
42	106.68	195.93	122.62	22.01	51.30
43	109.22	212.88	132.95	22.57	57.36
44	111.76	160.84	100.01	18.63	42.19
45	114.30	236.53	146.46	25.26	64.80
46	116.84	117.49	73.35	13.74	30.40
47	119.38	151.33	93.12	17.45	40.76
48	121.92	149.35	92.52	15.23	41.60
49	124.46	99.73	63.98	10.09	25.66
50	127.00	94.64	58.35	10.81	25.48
51	129.54	64.80	41.35	6.75	16.70
52	132.08	67.01	39.69	7.21	20.10
53	134.62	45.64	25.44	4.46	15.74
54	137.16	65.18	36.36	6.03	22.79
55	139.70	46.10	28.40	3.90	13.80
56	142.24	36.25	18.91	3.48	13.85
57	144.78	16.79	10.80	1.51	4.49
58	147.32	10.57	5.25	.60	4.72
59	149.86	32.50	21.37	3.47	7.66
60	152.40	--	--	--	--
61	154.94	--	--	--	--
62	157.48	12.26	8.26	1.09	2.91
63	160.02	--	--	--	--
64	162.56	28.63	17.61	2.71	8.31
65	165.10	12.31	6.47	.89	4.95
66	167.64	--	--	--	--
67	170.18	--	--	--	--
68	172.72	17.67	8.30	1.15	8.24
Total		10 268.75	6 537.31	1 136.87	2 594.58

The New Grading Rules

GENERAL SPECIFICATIONS

1. The grades are intended for 16-foot "log"[1/] lengths as commonly cruised in standing trees. If the cruise log length includes trim allowance, the specifications must be applied to the entire length.

2. The grades are not intended for application to cull logs (logs with more than a two-thirds cruise volume deduction).

3. Log diameter is not a specific grading criterion. The effect of log grade and size on value and product recovery is reflected in the tables.

4. Most of the grading specifications are applied by log "faces." A log face is one-quarter of the log circumference for the full length of the log.

5. A log adjacent to a cull log must be lowered one grade even if it meets specifications for grade 1, 2, or 3.

DEFINITIONS OF GRADING CHARACTERISTICS

1. *Knots* refer to sound, live, or dead limbs or limb stubs outside of knot cluster. Diameter of knot is measured at the log surface, inside the bark but outside the limb collar or swelling that may be present.

2. *Knot indicators* are bark distortions which indicate the presence of an underlying knot. Usually there is a small hole or depression in the center of the distortion. Indicator size is determined by the vertical diameter of the depression.

3. *Knot clusters* are three or more sound limbs or stubs, 1 inch or larger, in an inseparable group. The size of individual knots in a cluster is not considered.

4. *Cluster indicators* are three or more knot indicators, usually well defined by a distorted bark pattern and surface rise.

5. *Scars* are breaks in the normal bark pattern caused by injuries from fire, logging, frost, and lightning. They may be completely overgrown with callus tissue (old injuries), partially overgrown, or open (of recent origin). Their condition, location, and size determine whether they are *degrading* and therefore considered in the log grading specifications or superficial and disregarded.

1/ The term "log" refers to designated sections of standing trees.

(a) *Degrading scars:*
A scar is considered to be degrading when the underlying wood is decayed, excessively pitchy, severely checked, or otherwise injured to the extent that lumber or veneer recovery would be affected.

(b) *Superficial scars:*
A superficial scar is a shallow, open, and sound injury of relatively recent origin that, in the judgment of the cruisers, will not affect lumber or veneer recovery and therefore is disregarded. Small scars--6 by 6 inches or less--whether open or overgrown, are also considered to be superficial *providing they do not contain rot or are not located in the lower 8 feet of the butt log* (see scar specifications for grades 1 and 2).

6. *Conks* are the fruiting bodies of fungi and indicate presence of interior rot.

7. *Cankers* are lesions characterized by distorted bark, callus tissue, and pitch flow. Common causes are mistletoe and rusts.

8. *Rotten knots* are live or dead limbs or stubs showing rot. Rotten or "punky" knots are treated the same as conks.

9. *Sound burls* are round or elliptical woody growths that protrude abruptly from the log surface with no evidence of decay or pitch.

10. *Unsound burls* are characterized by evidence of decay or heavy pitch or both.

11. *Bumps and bulges* are bark-covered swellings on the log surface that do not conform to the normal taper or normal butt swell.

12. *Epicormic branches* are small, sprout-type limbs, that originate from dormant, usually 1/2-inch diameter or less, or adventitious buds.

13. *Holes* are the result of bird peckings or insect activity into the cambium.

APPLICATION OF GRADES

Cruisers (log graders) usually develop their own procedures for applying grading rules. Suggested steps are:

1. Size up each log with respect to knots, determining either the poorest (most shallow) or best (clearest) side.

2. Establish log grading faces based on the presence and character of any knots or indicators. Once the grading faces on a log are established, they cannot be shifted. Exception: see specifications for burls.

3. Apply knot or indicator specifications to determine preliminary grade of log; then apply other grading cirteria such as scars, conks, etc., to establish final grade. For example, if the log is knot free, it is a potential grade No. 1. The grader would then look for other possible limiting characteristics to establish the final grade.

A Summary of Specifications for the New Timber Cruising Grades for Coast Douglas-fir

<table>
<tr><th>Log characteristic</th><th>Grade No. 1[1]</th><th>Grade No. 2[1]</th><th>Grade No. 3[1]</th><th>Grade No. 4</th></tr>
<tr><td>Knots (sound)</td><td>One allowed if 1 inch or less,
or
one larger than 1 inch if within 6 inches of log end.</td><td>None allowed on two faces. Knots larger than 2 inches must be confined to upper or lower half of one face.</td><td rowspan="2">Knots (sound or rotten) larger than 3 inches must be confined to one face.</td><td rowspan="11">Any merchantable log not meeting requirements for grade No. 3.</td></tr>
<tr><td>Rotten knots</td><td>None allowed.</td><td>None allowed unless log is otherwise grade No. 1.</td></tr>
<tr><td>Knot indicators</td><td>If larger than 1 inch, must be confined to no more than two faces.</td><td colspan="2">No requirements.</td></tr>
<tr><td>Knot clusters</td><td>None allowed.</td><td>One if confined to one face.</td><td>Any number if confined to no more than two faces.</td></tr>
<tr><td>Knot indicator clusters</td><td>One if confined to one face.</td><td colspan="2">No requirements.</td></tr>
<tr><td>Scars</td><td>None allowed from ground line to 8 ft. Above 8 ft.: no limit for sound scars 6"x6" or smaller, larger sound scars must be confined either to one face or not more than two faces in any 1/4 of log length. No rotten scars allowed.</td><td>All scars having rot must be confined to one face.</td><td>No requirements.</td></tr>
<tr><td rowspan="2">Sound burls[2]</td><td colspan="3">Disregard burls if less than 6 inches in diameter.</td></tr>
<tr><td>If larger than 6-inch diameter, must be confined to one face.</td><td colspan="2">All larger than 6 inches must be confined to three faces.</td></tr>
<tr><td>Conks, cankers, and unsound burls</td><td>None allowed</td><td>None allowed unless log is otherwise grade No. 1.</td><td>No requirements.</td></tr>
<tr><td>Bumps and bulges</td><td>None 6"x6" or larger allowed from ground line to 8 feet. No requirement above 8 feet.</td><td colspan="2" rowspan="2">No requirements.</td></tr>
<tr><td>Epicormic branches and holes</td><td>Must be confined to one face.</td></tr>
</table>

[1] A log meeting specifications for either grade No. 1, 2, or 3 is lowered one grade if adjacent to a cull log.

[2] When burls are considered, log faces can be shifted from the faces initially established for knots or other characteristics.

Plank, Marlin E., and John W. Henley
1976. Lumber yields by the new timber cruising log grades for old-growth Coast Douglas-fir. USDA For. Serv. Res. Pap. PNW-203, 30 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Lumber grade yields and recovery ratios obtained for old-growth Coast Douglas-fir logs are presented for the new timber cruising log grades. Lumber yield information is based on nearly 5,000 logs processed through 10 sawmills in Washington, Oregon, and California. Curve relationships are shown for lumber grade recovery over diameter, scale recovery ratio over diameter, lumber recovery factor over diameter, and net Scribner and gross cubic scale defect over diameter for the four log grades. Tables provide information on lumber yield distribution by diameter class and lumber grade in addition to the foregoing.

KEYWORDS: Lumber recovery studies, old-growth Douglas-fir.

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1976
USDA FOREST SERVICE RESEARCH PAPER PNW-204

Estimation of Decay

in Old-growth Western Hemlock and Sitka Spruce in Southeast Alaska

MAR 88 ...

Wilbur A. Farr
Vernon J. LaBau
and
Thomas H. Laurent

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
PORTLAND, OREGON

Cover: *Fomes pinicola*, shown here on western hemlock, is responsible for about 22 percent of the internal decay in western hemlock and 73 percent of the decay in Sitka spruce (Kimmey 1956).

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Authors

During this study, Wilbur A. Farr, Vernon J. LaBau, and Thomas H. Laurent were mensurationists with the Pacific Northwest Forest and Range Experiment Station, Juneau, Alaska. LaBau is now a mensurationist with the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado; Laurent is a plant pathologist with Region 10 of the U.S. Forest Service, Juneau, Alaska.

ESTIMATION OF DECAY IN OLD-GROWTH WESTERN HEMLOCK AND SITKA SPRUCE IN SOUTHEAST ALASKA

Reference Abstract

Farr, Wilbur A., Vernon J. LaBau, and Thomas H. Laurent
1976. Estimation of decay in old-growth western hemlock and Sitka spruce in southeast Alaska. USDA For. Serv. Res. Pap. PNW-204, 24 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Trees on sixty seven 1/5th-acre plots were dissected so that a method could be developed for making unbiased estimates of decay in western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) on commercial forest land in southeast Alaska. Decay in both species was related to many variables, but relationships were weak. For hemlock, decay was best related to position of external indicators and to geographic location; decay in hemlock increased to the north. For spruce, the most useful predictor of decay was position of external indicators. These derived decay factors are useful for large-scale inventories; their reliability cannot be guaranteed on local timber sales.

KEYWORDS: Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*, decay (-log quality.

RESEARCH SUMMARY

Research Paper PNW-204

1976

The forests of southeast Alaska consist mostly of defective stands of old-growth western hemlock and Sitka spruce. On the average, total defect accounts for about 31 percent of the gross board-foot volume.

For the past 20 years, timber cruisers in the region have estimated wood loss in standing trees from tables of decay factors based on the location of external indicators of decay and tree diameter (Kimmey 1956). In some instances this has worked satisfactorily, but net scaled volume removed from sale areas often differs considerably from cruised net volume. Many factors contribute to these differences, but foresters in the region have for many years suspected that type and amount of decay is so variable from area to area that the decay factor tables themselves may be a significant source of error. So, a study of tree decay was begun on commercial forest land to see if an improved method for estimating decay in standing trees could be developed. Trees on sixty seven 1/5th-acre plots were felled and dissected.

External indicators such as basal and trunk scars, frost cracks, broken tops in the merchantable stem, conks, swollen knots caused by *Fomes pini*, rotten stubs, and rotten burls were found to be significantly related to internal decay in hemlock and spruce. Certain injuries and imperfections, like dead and broken tops above the merchantable stem, large dead branches

or sucker-type limbs, forked tops, dead sides, sound burls, sound mistletoe cankers, and conks more than a foot from the stem on branches, were not consistent indicators of decay. Most external indicators of decay were located on the lower stem; and when indicators were found on the upper stem, the tree usually had an indicator on the lower stem as well. Decay percentages in hemlock and spruce were significantly related to position of external indicators, tree age, and tree diameter, although the relationships were weak. Decay percentages in hemlock were also related to latitude.

Development of equations to predict decay was difficult, as coefficients of variation often exceeded 200 percent. Decay was highly variable and use of various tree characteristics in regression accounted for little of the total variation. Decay percentages in hemlock also generally increased from south to north, indicating that geographic location was an important variable. In the final analysis, the prediction equation for hemlock included just two variables--position of external indicator and geographic location (table 1). Constant or flat decay factors based solely on position of external indicators were developed for spruce (table 2).

The new decay factors are easier to apply than those used previously, since tree diameter need not be known. Rather, there is a table of constant or flat factors for each species. Development of a more complicated estimation procedure could not be justified.

Prospective users of these decay factors are cautioned that they were developed from data collected throughout southeast Alaska. Therefore, their reliability cannot be guaranteed if they are applied to local timber sales. They should only be used for large cruises and extensive inventories.

We believe there is no reliable way to obtain estimates of decay in standing hemlock and spruce trees on a sale basis in southeast Alaska unless sample trees are felled and sectioned.

Table 1--*Decay in percent of gross cubic- and board-foot volume in western hemlock in southeast Alaska by position of external indicator and geographic area*

Position of external indicator	Geographic area			
	Ketchikan	Petersburg	Sitka	Juneau
	- - - - - - - - *Percentage* - - - - - - - -			
Cubic-foot decay[1/]				
0 None	0	2.0	6.7	10.2
1 Above the first 32-foot log	8.4	10.4	15.2	18.7
2 On the first 32-foot log	12.4	14.4	19.2	22.7
3 Both on and above the first 32-foot log	29.1	31.1	35.8	39.4
Board-foot decay[2/]				
0 None	.9	6.3	13.7	22.4
1 Above the first 32-foot log	19.7	25.1	32.4	42.2
2 On the first 32-foot log	27.3	32.7	39.9	49.8
3 Both on and above the first 32-foot log	54.7	60.1	67.4	77.2

[1/] Based on the regression $Y = 8.44x_1 + 12.45x_2 + 29.13x_3 + 1.95x_4 + 6.71x_5 + 10.24x_6$, where $x_1 = 1$ for indicators above the first 32-foot log; $x_2 = 1$ for indicators on the first 32-foot log; $x_3 = 1$ for indicators both on and above the first 32-foot log; $x_4 = 1$ for trees in the Petersburg area; $x_5 = 1$ for trees in the Sitka area; $x_6 = 1$ for trees in the Juneau area; all are 0 otherwise. Standard error of estimate = 13.61 or 134.5 percent of the mean. $R^2 = 0.35$.

[2/] Scribner rule. Based on the equation $Y = 0.91 + 18.79x_1 + 26.37x_2 + 53.78x_3 + 5.41x_4 + 12.66x_5 + 22.47x_6$. Standard error of estimate = 26.67 or 119.4 percent of the mean. $R^2 = 0.35$.

Table 2--*Means and standard errors of decay percentages for Sitka spruce in southeast Alaska by position of external indicator*[1/]

Position of external indicator	Sample size	Cubic-foot decay		Board-foot decay (Scribner rule)	
		Mean decay percentage	Standard error of the mean	Mean decay percentage	Standard error of the mean
0 None	194	0.4	0.12	1.3	0.37
1 Above the first 32-foot log	9	7.8	4.70	15.6	8.39
2 On the first 32-foot log or, both on and above the first 32-foot log	42	16.0	2.73	33.9	4.75

[1/] Separation of the data into classes by position of external indicator accounted for 37 percent of the variation in cubic-foot decay percentages and 43 percent of the variation in board-foot decay percentages.

Introduction

Southeast Alaska consists of the Alexander Archipelago and a narrow mainland strip along the Pacific Ocean between 55° and 60° north latitude (fig. 1). Because of its rugged relief and proximity to the ocean, the area has a moist maritime climate with abundant rainfall throughout the year and infrequent periods of hot, dry summer weather.

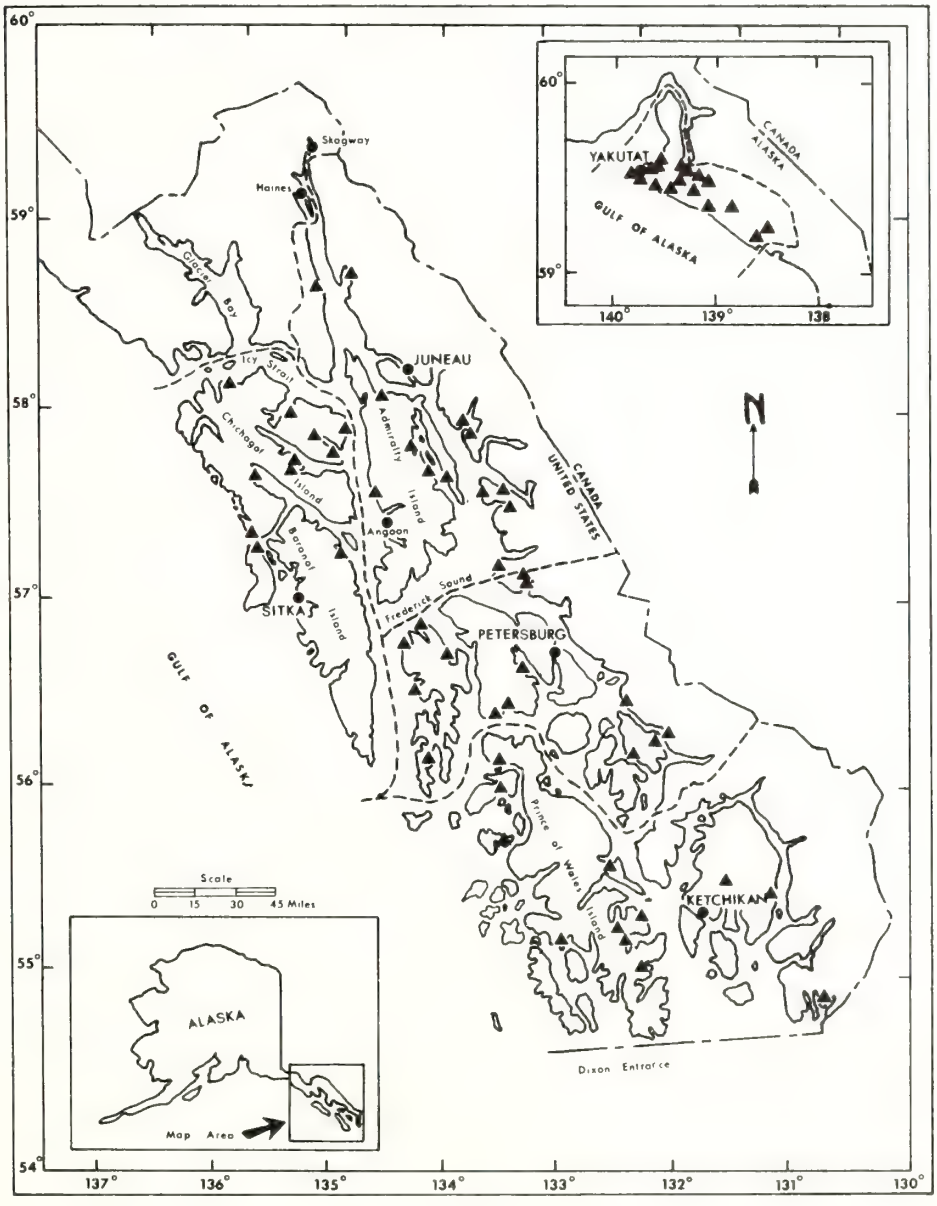

Figure 1.--Location of 67 cull study plots in southeast Alaska.

About 89 percent of the forest area of the region is in mixed stands of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) with the two species making up 64 and 28 percent, respectively, of the cubic-foot growing stock volume (Hutchison 1967). Appearance and condition of these stands vary considerably, but most are defective, with total defect accounting for about 31 percent of the gross board-foot volume.[1/] Because of the large amount of defect and great variation in decay, it is difficult for cruisers to estimate net volumes of standing trees. In years past when timber values were relatively low, it was sufficient for sales purposes to have approximate estimates of net volume; but now it is becoming increasingly important that more precise estimates be obtained.

Timber cruisers in southeast Alaska generally use tables to estimate decay in standing trees, based on the location of external indicators and tree diameter (Kimmey 1956). Kimmey's tables, however, seem best suited to large-scale surveys where decay percentages tend to average out. Because of large standard errors associated with these tables, biased estimates often result when they are applied to small sales.

In 1961, Bones[2/] tested Kimmey's tables on 21 active logging shows. He found that scaled net volume on a sale basis ranged from 30 to 143 percent of cruised net volume, but that total cruised net volume for all sales combined was only 2.1 percent higher than total scaled net volume, indicating that the decay factors provided a useful measure of total decay when applied over a large area. However, the factors tended to overestimate decay in western hemlock and underestimate decay in Sitka spruce. Decay in western redcedar (*Thuja plicata* Donn) was greatly overestimated.

The study reported here was started in the late 1960's to develop a method for making unbiased estimates of decay for hemlock, spruce, and cedar on commercial forest land[3/] in southeast Alaska. However, only the hemlock and spruce data were analyzed, as there were too few cedars sampled. Data collected by Kimmey in the 1950's were also reanalyzed, but the two sets of data were not pooled, as merchantability standards and sampling methods were different for each study.

Preliminary results of the study were reported by LaBau and Laurent (1974). Included here are new decay factors for hemlock and spruce, along with measures of their precision. The new factors are easier to apply than those used previously since tree diameter need not be known. This study shows that decay in western hemlock and Sitka spruce in southeast Alaska is highly variable and not easily estimated. External indicators of decay and various tree characteristics are significantly but weakly correlated with percentage of interior decay. Use of broad constant or flat factors to estimate decay are as useful as more complicated functions.

[1/] Forest survey statistics on file at the Forestry Sciences Laboratory, Juneau, Alaska.

[2/] Bones, J. T. 1964. Estimating cull in southeast Alaska tree species. Unpublished report. For. Sci. Lab., Juneau, Alaska.

[3/] Commercial forest land is defined as land available for timber production and capable of growing stands containing 8,000 board feet (International 1/4-inch rule) of timber per acre (Hutchison 1967).

Past Investigations

A general lack of knowledge concerning the biology of forest fungi in hemlock and spruce and amounts of associated decay has led to many disease studies in British Columbia and the Pacific Northwest. Few detailed studies of tree diseases have been conducted in southeast Alaska. Only the most important literature will be reviewed here, as a detailed summary was recently published (Laurent 1974).

Relative importance of rot fungi attacking hemlock and spruce changes with latitude and elevation (Buckland 1946, Englerth 1942, Foster et al. 1958, Kimmey 1956, 1964, 1965). *Echinodontium tinctorium* (Ellis and Everh.), the Indian paint fungus, for example, causes severe damage to western hemlock in northern Idaho and upper Columbia region of British Columbia (Foster et al. 1954, Weir and Hubert 1918), little damage in Oregon and Washington (Englerth 1942), and none in southeast Alaska. The species, however, has been reported in mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) in Prince William Sound (Ellis 1895). *Fomes pinicola* (Swartz ex Fr.) Cke., a major cause of decay in southeast Alaska (Kimmey 1956), is a scavenger fungus in the Pacific Northwest States and not a major cause of decay in living trees (Englerth 1942).

Fomes pini (Thore ex Fr.) Karst is also of lesser importance in southeast Alaska than in the contiguous Pacific Northwest States and British Columbia. Decay resulting from this fungus lessens northward and westward and switches to mountain hemlock, suggesting that the importance of this fungus changes with latitude and altitude.

Decay organisms responsible for rot in the coastal forests are mostly heart- and root-rotting fungi which cause large losses of wood plus increased logging and milling costs. Although many species are present, they can be grouped into two broad classes, the white rots and the brown rots. This classification is a bit loose, but generally the white rots are caused by fungi that decompose all components of the wood and the brown rots, by fungi that attack the cellulose, leaving the lignin more or less unaffected. Wood attacked by the white rot fungi is sometimes usable for pulp in the early stages of decay, but wood attacked by brown rot fungi is useless for pulp or construction. Kimmey (1956) estimated 22 percent of the western hemlock and 4 percent of the Sitka spruce cubic-foot decay to be incipient white rot.

Roots, wounds, and branch stubs serve as the main infection courts for decay fungi attacking western hemlock and Sitka spruce. When conks of these decay fungi are found, the organism can be readily identified. Unfortunately, relatively few conks are produced on living trees in the Queen Charlotte Islands (Bier et al. 1946, Foster and Foster 1952) or in coastal Alaska.

Studies of forest diseases in Alaska began in the 1930's when the late Dow Baxter, then professor of Forest Pathology at the University of Michigan, began making periodic survey and collecting trips to both interior and coastal Alaska. Little use was being made of the timber at the time, and the forest disease information was mainly of academic interest. Demand however, changed in the early 1940's as high-quality

Sitka spruce was then sought for aircraft construction (American Forests 1942, Johnson 1943). The need for high-quality saw logs generated interest in Sitka spruce diseases, as experience showed that certain defects and poor handling resulted in a great waste of effort and material. A high percentage of the timber was found unsuitable for aircract construction. Information obtained by Baxter on several trips to southeast Alaska (Baxter 1947) and laboratory tests of relative rates of growth of various fungi provided the basis for recommendations on how to select and transport high-quality spruce logs (Baxter and Varner 1942).

Englerth (1947) also contributed to our knowledge of Sitka spruce decays during this period. In response to a request from the Alaska Spruce Log Program, Englerth spent part of 1942 and 1943 in southeast Alaska, developing techniques to aid cruisers, fallers, and buckers in recognizing and evaluating decay in Sitka spruce trees and logs. Four fungi, *Polyporus schweinitzii* Fr., *P. borealis* Fr., *Fomes pinicola*, and *P. sulphureus* (Bull.) Fr., caused 78 percent of infections in spruce. Conks were produced infrequently or not at all on living trees and in most instances frost cracks, scars, and broken tops provided the only basis for estimating presence of decay. A comparison of slow- and fast-growing trees showed no difference in volume lost through decay.

In 1950, Klein (1951) collected general information on decay and recorded many of the tree diseases found in western hemlock, Sitka spruce, and western redcedar in southeast Alaska.[4/] [5/] He also found that visible defect was related to site, diameter, and species but not to tree age or vigor. Spruce had little decay in the smaller diameter classes and relatively few cull trees.

Then in 1953, James Kimmey initiated a study of decay in standing trees as part of a general forest disease survey of Alaska. His work was a direct result of the need for decay information to strengthen the timber resource inventories in the region. Results of Kimmey's (1956) study were used for forest inventory and by 1960 were incorporated by the Forest Service into presale cruising procedures in southeast Alaska. Diameter at breast height and position of visible indicators were used to predict percentage of rot in standing hemlock, spruce, and western redcedar in southeast Alaska. Less reliable constant or flat factors based only on tree diameter were also presented.

Indicators of decay included conks, swollen knots caused by *Fomes pini*, scars, frost cracks in the main stem, rotten stubs and old dead tops protruding from the lower main stem, and rotten burls or cankers. Dead or spike tops, sucker-type limbs, dead sides, forked tops, sound mistletoe cankers, and conks more than 1 foot from the stem on limbs were abnormalities that did not consistently indicate the presence of decay. Other abnormalities not associated with decay were large mistletoe limbs, black knots, and sound burls on hemlock and large dead limbs and knotty stems on spruce.

[4/] Klein, J. A. 1951. Diseases of southeast Alaska timber trees. Unpublished first progress report, 59 p. For. Sci. Lab., Juneau, Alaska.

[5/] Klein, J. A. 1951. Defect in the climax forests of southeast Alaska. Unpublished report, 8 p., illus. For. Sci. Lab., Juneau, Alaska.

In western hemlock 10 decay-associated fungi were identified; 10 were also identified in spruce. Three of the 10 in hemlock, *Armillaria mellea* (Vahl ex Fr.) Quel., *F. pinicola*, and *F. annosus* (Fre.) Cke. caused 25.9, 22.2, and 20.5 percent, respectively, of the total cubic-foot standing tree decay. In Sitka spruce, *F. pinicola* caused 73.3 percent of the cubic-foot decay.

Foresters in British Columbia have also placed emphasis on the development of tables and equations to predict decay in standing trees as part of their forest inventory program. The effects of tree age and diameter, site, log grade, and physiographic location on presence of decay in trees have been most commonly studied (Bier and Foster 1946a, 1946b, Bier et al. 1946, Foster and Foster 1952, Browne 1956, Foster 1957).

The Study

FIELD PROCEDURES

Field data were collected on sixty seven 1/5-acre plots scattered over southeast Alaska on commerical forest land (fig. 1). Plots were chosen at random from about 680 forest inventory locations established in the mid- to late-1950's. Except for a few dangerous culls, all trees 5 inches d.b.h. and larger on each plot were felled and sectioned so that tree volumes and extent of internal decay could be determined; in all, 1,600 trees were cut. The analysis was based only on data from 532 sawtimber hemlock and 245 sawtimber spruce, all 11.0-inch d.b.h. and larger. Smaller trees, trees with forks in the main stem, and cedar were excluded.

Latitude and elevation were recorded for each plot. Tree species, diameter and age at breast height, and crown class and vigor were noted for each tree on the plots. Where applicable, number of indicators per tree, type, length, width, diameter, aspect, and position on the stem were also recorded before the trees were felled and sectioned.

Felled trees 11.0-inch d.b.h. and larger were sectioned at 16.3-foot intervals above a 1.0-foot stump, with additional cuts at breast height, midpoint of the first log, at a point where diameter inside bark equaled 40 percent of the diameter at breast height (merchantable top), and at the 6.0- and 4.0-inch tops inside bark. Additional cuts were often made to determine extent of incipient and advanced decay and to evaluate importance of external indicators. When incipient[6/] or advanced[7/] decay was found, the area affected was measured so that decay in trees could be calculated by cubic- and board-foot rules.

[6/] Incipient decay is the earliest stage of decay when the wood appears hard and firm but has a slight color change. Low grades of lumber may be manufactured from such wood, and it may be used for pulp although there may be some weakening of the fibers.

[7/] Advanced decay is a later stage when the wood is noticeably changed in structure and appearance. Strength is so reduced that the wood can usually be easily crumbled.

ANALYSIS

Gross and net tree volumes were calculated from a computer program developed to process decay data.[8/] Cubic-foot volumes were computed between a 1.0-foot stump and a 4.0-inch top inside bark, while board-foot volumes (Scribner rule) were computed for 16.3-foot logs between a 1.0-foot stump and a top equal to 40 percent of the diameter at breast height, but not less than 6.0 inches inside bark.

Cubic- and board-foot defect included both incipient and advanced decay. Some sound wood was usually included. The amount depended upon the nature of the decay and scaling rules[9/] applied. Sound wood defects such as broken tops, sweep, crook, shake, frost cracks, breakage, and fluting were not included in the cubic-foot deductions.

For board-foot decay, any 16-foot log that squared out over two-thirds defective was culled 100 percent. In addition to incipient and advanced decay, deductions were made for the sound-wood defects of shake and frost cracks.

Significant external indicators of decay were identified; then regression analysis was used to develop equations to predict decay percentages in standing trees. In regression analysis many variables were considered singly and combined.

Selection of important independent variables was complicated by the amount of variation in the decay data, as standard errors expressed as a percent of mean decay often exceeded 200 percent.

In the analysis, individual trees were treated as independent observations even though trees were actually sampled in groups on 1/5-acre plots.

External Indicators of Decay

Mean decay percentage in trees without external indicators was first calculated to establish a norm against which decay in trees with indicators could be compared. Mean decay percentage for trees with a specific type of indicator was then statistically compared to the sample of trees without indicators to see if the indicator was significantly related to internal decay (table 3).

Indicators found important were basal scars (fig. 2) and trunk scars (fig. 3) extending into the heartwood, frost cracks (fig. 4), broken tops in the merchantable stem (fig. 5), and conks (fig. 6). The same indicators were important in Kimmey's (1956) study. Other potential indicators such as swollen knots, caused by *Fomes pini*, rotten stubs, and rotten burls could not be evaluated as there were insufficient samples. However, these were considered significant indicators of decay in Kimmey's study, and we

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[8/] Computer program ACUL, on file at Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

[9/] Scaling rules are described in Forest Service Handbook 2443.71, "National Forest Log Scaling Handbook," USDA For. Serv.

Table 3--*Decay percentage in western hemlock and Sitka spruce in southeast Alaska by type of indicator*

Indicator	Trees with indicators		Decay percentage associated with a single type of indicator	
	Number[1/]	Percent	Cubic feet	Board feet[2/]
Western Hemlock:				
Basal scar	56	10.5	19.3	43.8
Trunk scar	129	24.2	13.2	31.9
Frost crack	22	4.1	7.2	17.0
Broken top[3/]	16	3.0	21.8	42.4
Conk	9	1.1	(4/)	(4/)
None	344	64.7	4.2	10.5
Total sample	532	--	--	--
Sitka Spruce:				
Basal scar	8	3.3	15.6	31.0
Trunk scar	22	9.0	13.3	29.3
Frost crack	19	7.8	22.2	36.8
Broken top[3/]	5	2.0	(4/)	(4/)
Conk	11	3.3	12.0	25.2
None	194	79.2	.4	1.3
Total sample	245	--	--	--

[1/] Some trees have more than one indicator, so the total of all trees with and without indicators does not add up to total number of trees.

[2/] Scribner rule.

[3/] Broken top extending into merchantable sawtimber stem.

[4/] Insufficient sample to calculate a meaningful average.

Figure 2.--Basal scars are open or closed injuries which penetrate the heartwood below the 1-foot stump and often extend above into the merchantable stem. Recent injuries less than 5 years old do not indicate decay.

Figure 3.--Trunk scars in the lower stem of western hemlock. Trunk scars are open or closed injuries penetrating the heartwood of the merchantable stem starting above the 1-foot stump.

Figure 4.--Frost crack in the lower stem of western hemlock with associated decay.

Figure 5.--Broken top within the merchantable stem is an indicator of decay.

Figure 6.--Fomes pini on the lower stem of western hemlock. Any conks on the main stem are indicators of decay.

Figure 7.--Black knots commonly found on western hemlock are not indicators of decay. Other imperfections that do not indicate decay are dead or broken tops above the merchantable stem, large dead branches or sucker-type limbs, forked tops, dead sides, sound burls, and conks more than 1 foot from the stem on branches.

considered them significant in our study as well. Trunk scars extending into the heartwood were the most commonly found indicators, followed by basal scars in hemlock and frost cracks in spruce. Conks were infrequently found, especially at lower elevations. A general observation was that *Fomes pini* conks are more common at higher elevations, although no supporting data exist. Trees with indicators averaged 1.8 indicators per tree for hemlock and 2.1 for spruce.

Certain injuries and imperfections in hemlock and spruce are not consistent indicators of decay. These include dead or broken tops above the merchantable stem, large dead branches or sucker-type limbs, forked tops, dead sides, sound burls, and conks more than 1 foot from the stem on branches. Black knots, commonly found on hemlock, are not indicators of decay (fig. 7).

About 65 percent of the hemlock and 79 percent of the spruce had no external indicators (table 4), and average defect for those trees was low.

Table 4--*Occurrence of sawtimber sample trees and presence of decay indicators*

Species and source of date	Trees with no indicators		Trees with indicators on:					
			Upper stem[1/]		Lower stem[2/]		Both upper and lower stem	
	No.	*Percentage*	*No.*	*Percentage*	*No.*	*Percentage*	*No.*	*Percentage*
Hemlock:								
This study	344	65	34	6	111	21	43	8
Kimmey (1956)	154	67	16	7	42	18	18	8
Spruce:								
This study	194	79	9	4	29	12	13	5
Kimmey (1956)	150	65	22	10	36	16	22	10

[1/] Above the first 32-foot log.

[2/] On the first 32-foot log.

The high percentage of trees with no indicators was due to sampling, as fixed plots were used in which the frequency distribution was heavily weighted to trees of smaller diameter. Decay generally increases with diameter and age, so when decay percentage is calculated on a volume basis there is more total decay than number of trees with indicators would suggest.

Distribution of sample trees by position of external indicator is also shown in table 4 contrasted with data obtained by Kimmey (1956). Distribution of trees in the two studies was similar, even though Kimmey collected his data from eight logging shows at sea level instead of at random from all commercial forest land.

Most external indicators were found on the lower stem; and when a tree had an indicator on the upper stem, it usually had an indicator on the lower stem as well. The important point is that most trees in both studies had no external indicators, and variation in decay among those that did was considerable.

Other Variables Related to Decay

Tree age.--Decay percentages were significantly related to tree age (fig. 8). Hemlock and spruce less than about 100 years of age are generally sound, but older hemlock deteriorates at a faster rate than spruce. At 300 to 400 years of age, spruce is relatively free of rot; whereas decay in hemlock averages 30 to 40 percent on a board-foot basis. Meaningful data were lacking beyond about 400 years of age. Decay percentages based on the board-foot scale were roughly twice those based on the cubic-foot scale.

The approximate relationships between decay percentages and tree age, shown in figure 8, are for data grouped by 50-year age class. Correlations were very weak, accounting for less than 12 percent of the variation for both cubic- and board-foot decay percentages of both species. Curves were fit by eye to hemlock data, as more precise fits would require solutions to nonlinear equations. This was not justified as it is not practical to use age as a predictor of defect in rotten trees.

Figure 8 gives the impression that decay in spruce is more variable than in hemlock but this is not the case. Trends were less well defined for spruce because there were fewer observations. No attempt was made to fit a curve to the spruce data.

Tree diameter.--Amount of decay was significantly related to tree diameter, but the relationships were weak. For hemlock, 9 percent of the variation in percent cubic-foot decay and 6 percent in percent board-foot decay was accounted for, and for spruce, 4 and 4 percent, respectively. Although correlations were weak, trends were clear when data were grouped by 4-inch diameter class (table 5).

Probability of occurrence of decay increases greatly with tree diameter, especially for hemlock. More than 50 percent of the hemlock over 23 inches had external indicators, and decay averaged 44 percent on a board-foot basis. Spruce was much less defective.

Kimmey (1956) used tree diameter and position of external indicators to predict decay percentages in standing trees. He first sorted his data by position of external indicator into the following classes:

--No external indicator
--External indicators either on or above the first 32-foot log
--External indicators both on and above the first 32-foot log

He showed graphically that decay percentages were related to tree diameter within indicator class, and then he prepared tables for each species showing cubic- and board-foot decay percentages by indicator class and tree diameter.

Kimmey's basic data were reanalyzed using computer programs not available to him at the time, and our conclusions are that:

1. Hemlock trees with indicators on either the upper or lower stem were correctly pooled into one class; and decay percentage was significantly related to tree diameter for trees with indicators either on or above the

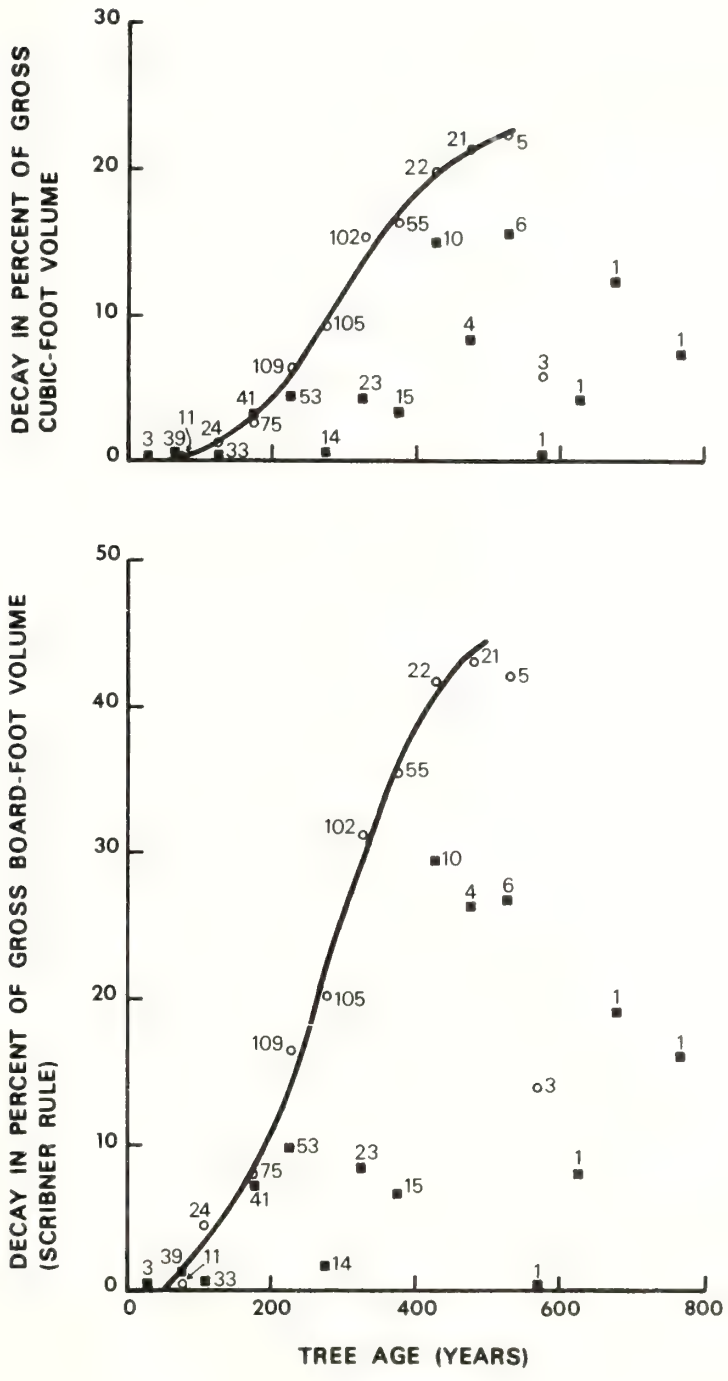

Figure 8.--Relationships between cubic- and board-foot decay percentages and tree age for all sample trees. Basic data were averaged by 50-year age class. Solid free hand curves and circles (o) are for western hemlock, squares (■) for Sitka spruce.

Table 5--*Decay percentage in western hemlock and Sitka spruce in southeast Alaska by 4-inch diameter classes*

D.b.h. (Inches)	Trees	Trees with indicators	In trees with no indicators		In trees with indicators	
			Cubic feet	Board feet 1/	Cubic feet	Board feet 1/
	Number		*Percentage*			
Western Hemlock:						
11-13	126	17.5	1.7	5.7	15.0	41.9
14-17	137	21.9	3.3	8.5	18.0	44.6
18-21	117	43.6	7.5	17.7	18.4	40.3
22-25	71	54.9	5.9	12.8	22.4	35.2
26-29	47	48.9	8.5	17.4	23.3	44.0
30-33	19	68.4	5.4	13.5	32.9	57.3
34-37	7	57.1	0.0	1.3	28.0	45.5
38-41	6	66.7	11.0	24.0	26.9	50.8
42-45	2	100.0	--	--	25.2	50.0
All trees	532	35.4	4.2	10.5	20.9	43.9
Sitka Spruce:						
11-13	35	14.3	0.2	1.0	1.1	4.9
14-17	32	18.8	.1	.2	3.1	5.9
18-21	58	13.8	.1	.2	23.9	47.9
22-25	33	18.2	.5	1.2	9.8	27.2
26-29	24	25.0	.1	.2	14.2	30.3
30-33	19	15.8	1.7	3.8	10.6	19.0
34-37	8	37.5	1.0	2.2	9.6	22.3
38-41	18	33.3	.3	.8	9.9	21.0
42-45	8	37.5	1.3	1.4	23.0	43.3
46-49	4	25.0	4.4	24.3	.4	6.0
50+	6	66.7	1.2	2.5	25.5	43.8
All trees	245	21.0	.4	1.3	14.6	30.7

1/ Scribner rule.

first 32-foot log, although the correlations were very weak. The relationship was nonsignificant for trees with indicators both on and above the first 32-foot log and a constant or flat factor should have been used. There were only 20 trees in the class; with the large amount of variation it was not possible to show a significant correlation between decay percentage and tree diameter.

2. The only significant correlation found for spruce was for trees without indicators. All other cubic- and board-foot correlations between decay percentage and tree diameter were nonsignificant and constant or flat decay factors should have been used.

When hemlock and spruce data from the current study were analyzed in the same way, only trees without indicators showed significant but weak correlations between percent decay and tree diameter. All others were nonsignificant, indicating that constant or flat factors should be used or some form of improved model developed using other combinations of variables.

Latitude and elevation.--Hemlock is generally most defective in the northern areas of southeast Alaska (table 6). This holds for trees with or without external indicators. Lower mean decay at Yakutat, an area of youthful, glacial outwash soils, was attributed to tree age. Hemlock at Yakutat were much younger and sounder than hemlock felled in other geographical areas of southeast Alaska.

Table 6--*Mean decay in western hemlock and Sitka spruce in southeast Alaska by geographic area*

Geographic area	Mean latitude of sample plots in degrees	Number of trees	Mean percentage decay in all sample trees ±standard error	
			cubic-feet	board feet[1/]
Western Hemlock:				
Yakutat	59.4	41	5.6 ± 2.11	12.3 ± 3.23
Juneau	57.9	149	17.2 ± 1.66	37.4 ± 3.21
Sitka	57.8	97	10.7 ± 1.98	21.6 ± 3.45
Petersburg	56.6	175	8.0 ± 1.01	18.3 ± 2.15
Ketchikan	55.5	111	3.5 ± .82	9.0 ± 1.79
Sitka Spruce:				
Yakutat	59.4	152	2.9 ± .74	6.7 ± 1.46
Juneau	57.9	34	5.9 ± 2.30	11.9 ± 4.16
Sitka	57.8	33	1.7 ± 1.47	3.2 ± 2.50
Petersburg	56.6	19	6.2 ± 2.50	14.3 ± 5.03
Ketchikan	55.5	7	1.2 ± .91	1.7 ± 1.13

[1/] Scribner rule.

The great difference in average decay for trees in the Juneau and Sitka areas, both at similar latitude, is probably due to differences in climate. Most plots in the Juneau area were located along the narrow mainland strip where growing season temperatures are cooler than in the islands further west. In hemlock, latitude accounted for 8 percent of the variation in percentage of both cubic-foot and board-foot decay.

Most commercial forest land in southeast Alaska is located below 500 feet, so a meaningful analysis of the effect of elevation was not possible. Only three of the study plots were located above 500 feet. For the hemlock data, percentage of cubic-foot decay was negatively correlated with elevation indicating lower decay at higher elevations than at sea level; but only 5 percent of the variation was accounted for. For spruce the correlation between decay percentage and elevation was nonsignificant.

Development of Prediction Equations

Simple regression.--In addition to variables already mentioned, others were analyzed both singly and in combination, including slope and aspect of the field plots, crown position, crown condition, and radial growth of each tree, presence or absence of external and specific indicators, and total number of indicators. Singly, most variables were highly significantly correlated with decay percentages; but relationships were weak, accounting for only 2 to 40 percent of the variation (table 7). Considerable unexplained variation remained. In fitting equations, all measurements were treated as separate observations.

Means, standard deviations (S), and standard errors (SE) of the raw data before regression analysis were as follows:

	Number of trees	Percentage of cubic-foot decay			Percentage of board-foot decay (Scribner rule)		
		Mean	±S	±SE	Mean	±S	±SE
Hemlock	532	10.1	16.82	0.73	22.3	32.91	1.43
Spruce	245	3.4	9.80	.63	7.4	18.83	1.20

The coefficient of variation (S ÷ mean), for example, for average percentage of cubic-foot decay in hemlock was 166.5 percent. It was apparent that high standard deviation and low correlations would make predictions of decay in individual trees imprecise. This poor showing, however, is probably typical of data collected in cull studies, though seldom reported.

Considered singly, the variables accounted for up to 28 percent of the variation in percentage of hemlock board-foot decay and up to 40 percent for spruce (table 7). Standard deviations about regression remained high, especially for percentage of board-foot decay. The most important variables were position and number of external indicators.

Table 7--*Coefficients of determination and standard deviations of simple linear regression for estimating decay in percent of gross cubic- and board-foot (Scribner rule) volume in western hemlock and Sitka spruce in southeast Alaska*

Independent variable	Western hemlock				Sitka spruce			
	Percentage cubic-foot decay		Percentage board-foot decay		Percentage cubic-foot decay		Percentage board-foot decay	
	Coefficient of determination[1/]	Standard deviation from regression	Coefficient of determination[1/]	Standard deviation from regression	Coefficient of determination[1/]	Standard deviation from regression	Coefficient of determination[1/]	Standard deviation from regression
1. D.b.h.	0.09**	16.1	0.06**	32.0	0.04**	9.6	0.04**	18.5
2. Age	.11**	15.9	.11**	31.1	.08**	9.4	.08**	18.1
3. Elevation	.05**	16.4	.03**	32.5	.01	9.8	.01	18.8
4. Aspect	.00	16.8	.00	32.9	.02*	9.7	.02*	18.6
5. Slope	.003	16.8	.002	32.9	.02*	9.7	.02*	18.6
6. Latitude	.09**	16.1	.08**	31.5	--	--	--	--
7. Crown position	.01**	16.7	.02**	32.7	.00	9.8	.00	18.9
8. Crown condition	.07**	16.2	.07**	31.7	.04**	9.6	.04**	18.4
9. Best 10-year radial growth	.07**	16.2	.07**	31.8	.04**	9.6	.05**	18.4
10. Indicator codes 0, 1, 2, 3	.28**	14.3	.28**	28.0	.34**	8.0	.40**	14.6
11. Presence or absence of indicators	.22**	14.8	.24**	28.8	.34**	8.0	.40**	14.6
12. Number of indicators	.25**	14.6	.25**	28.5	.35**	7.9	.39**	14.8
13. Geographic area	.09**	16.1	.09**	31.4	.00	10.9	.00	20.1

[1/] Indicates the proportion of the variation in decay percentage that is associated with the regression.

** Significant at the 1-percent level of probability.
* Significant at the 5-percent level of probability.

Multiple regression.--Several combinations of independent variables were tested in multiple regression, but even the best models did a poor job of predicting decay. Maximum variation accounted for in board-foot decay percentage was 34 percent for hemlock and 46 percent for spruce. Much residual variation remained, and most models were biased.

Diameter at breast height was significant when considered alone but in multiple regression was nonsignificant or of little value. Use of a presence or absence code essentially separated the data into two groups, trees with external indicators and trees without. Some additional precision was gained by knowing total number of indicators on a tree (table 8).

Table 8--*Simple and multiple linear regression for estimating decay in percent of gross cubic- and board-foot (Scribner rule) volume in western hemlock and Sitka spruce in southeast Alaska*

Regression equation Y = estimated decay in percent of gross cubic-foot volume	Coefficient of determination1/	Standard deviation from regression	Regression equation Y = estimated decay in percent of gross board-foot volume	Coefficient of determination1/	Standard deviation from regression
Western Hemlock:					
Y = 4.93 + 0.7845 (d.b.h.)	0.09**	16.1	Y = -1.46 + 1.2412 (d.b.h.)	0.06**	32.6
Y = 8.25 + 16.60 (POA)2/	.22**	14.8	Y = 10.54 + 33.40 (POA)2/	.24**	28.8
Y = 5.28 + 7.77 (Number of indicators)	.25**	14.6	Y = 12.86 + 15.24 (Number of indicators)	.25**	28.5
Y = -262.67 + 4.69 (Latitude) + 12.65 (Trunk scars) + 11.41 (Basal scars) + 20.57 (Broken top) + 12.85 (Frost cracks) + 20.57 (Conks)	.37**	13.4	Y = -489.75 + 8.80 (Latitude) + 26.43 (Trunk scars) + 21.14 (Basal scars) + 29.22 (Broken top) + 24.05 (Frost cracks) + 34.90 (Conks)	.34**	26.9
Sitka Spruce:					
Y = -1.19 + 0.1865 (d.b.h.)	.04**	9.6	Y = -1.49 + 0.362 (d.b.h.)	.04**	18.5
Y = 0.44 + 14.13 (POA)2/	.34**	8.0	Y = 1.26 + 29.41 (POA)2/	.40**	14.6
Y = 1.29 + 4.89 (Number of indicators)	.35**	7.9	Y = 3.16 + 0.984 (Number of indicators)	.39**	14.8
Y = 0.51 + 10.45 (Trunk scars) + 8.01 (Basal scars) + 13.92 (Frost cracks) + 18.06 (Conks)	.42**	7.5	Y = 1.55 + 20.66 (Trunk scars) + 19.37 (Basal scars) + 29.16 (Frost cracks) + 33.18 (Conks)	.46**	13.9

1/ Indicates the proportion of the variation in Y that is associated with the regression.

2/ Presence or absence of external indicators. POA = 1 if indicators are present; 0 otherwise.

** Significant at the 1-percent level of probability.

Prediction equations were also developed which included specific indicators of decay such as presence or absence of trunk scars, basal scars, etc. (table 8). These equations accounted for more variation than did other combinations of variables; but field application would tend to introduce biases as important individual indicators might easily be missed, resulting in an underestimate of decay.

The hemlock decay data showed a definite south to north gradient (tables 6 and 8). This suggested that decay prediction equations for hemlock would be biased unless the gradient effect was taken into account. Also the gradient did not seem to be strictly related to latitude, but to differences in climate as explained earlier.

Decay percentages were also related to location of external indicators, and most differences between classes were significant (table 9).

Table 9--*Means and standard errors of decay percentages in western hemlock and Sitka spruce in southeast Alaska by position of external indicator*

Position of external indicator	Sample size	Cubic-foot decay		Board-foot decay (Scribner rule)	
		Mean decay percentage	Standard error of the mean	Mean decay percentage	Standard error of the mean
Western Hemlock:[1/]					
0 None	344	4.2	0.55	10.5	1.29
1 Above the first 32-foot log	34	13.6 [2/]	2.79	30.6	5.87
2 On the first 32-foot log	111	18.1	1.77	39.7	3.23
3 Both on and above the first 32-foot log	43	34.0	3.64	65.6	5.17
Sitka Spruce:[3/]					
0 None	194	.4	.12	1.3	.37
1 Above the first 32-foot log	9	7.8	4.70	15.6	8.39
2 On the first 32-foot log	29	16.4	3.31	35.1	5.63
3 Both on and above the first 32-foot log	13	15.1	5.00	31.2	9.12
Classes 2 and 3 combined[4/]	42	16.0	2.73	33.9	4.75

[1/] Separation of data into classes by position of external indicator accounted for 30 percent of the variation in cubic-foot decay percentage and 29 percent of the variation in board-foot decay percentage.

[2/] Any two means not joined by the same line are significantly different. Any two means joined by the same line are not significantly different at the 95-percent level of probability.

[3/] Separation of data into classes by position of external indicator accounted for 37 percent of the variation in cubic-foot decay percentage and 43 percent of the variation in board-foot decay percentage.

[4/] For spruce, means in classes 2 and 3 are not significantly different. The two classes should be combined since trees with indicators on both the upper and lower stems should on the average have more decay than trees with indicators only on lower stem. This, then, defines three classes of trees--those with no indicators, those with indicators above the first 32-foot log, and those with indicators on the first 32-foot log or with indicators both on and above the first 32-foot log.

Multiple regression with dummy variables.--After several models were tested, it was concluded that a straight-forward solution would be to develop an equation based upon smoothed class means. This was possible as the two most important independent variables--position of the external indicators and geographical area--were both qualitative variables, each at four levels as follows:

Position of external indicator	Geographical area
0 None	1 Ketchikan
1 Above the first 32-foot log	2 Petersburg
2 On the first 32-foot log	3 Sitka
3 Both on and above the first 32-foot log	4 Juneau

Relationships between decay percentages and the two independent variables were developed by solving the general equation:

$$Y = b_0 + b_1x_1 + b_2x_2 \ . \ . \ . \ + b_6x_6$$

where: Y = percent of gross volume that is decay;

x_1 = 1 for indicators above the first 32-foot log, 0 otherwise;

x_2 = 1 for indicators on the first 32-foot log, 0 otherwise;

x_3 = 1 for indicators both on and above the first 32-foot log, 0 otherwise;

x_4 = 1 for trees in the Petersburg Unit, 0 otherwise;

x_5 = 1 for trees in the Sitka Unit, 0 otherwise;

x_6 = 1 for trees in the Juneau Unit, 0 otherwise;

b_i = regression constants.

The constant term b_0 was an estimate of Y for trees without indicators in the Ketchikan Unit. Additional variables like tree diameter and interactions between diameter and indicator code were also tested and discarded as they were not important.

This equation worked reasonably well with hemlock but not for spruce, probably because there were too few spruce samples in most classes and variability of the data was too great. Spruce is sounder than hemlock, and trees with several indicators often had little defect.

Mean decay percentages for hemlock before regression had few observations in many cells (table 10). Regression solutions for hemlock, shown below, and given in tabular form in table 1, effectively smoothed the cell values.

Hemlock percent cubic-foot decay

$$Y = 8.44x_1 + 12.45x_2 + 29.13x_3 + 1.95x_4 + 6.71x_5 + 10.24x_6$$

$$R^2 = 0.35^{10/}$$

10/ R^2 is the proportion of total variation about the mean ($\bar{Y}$) that is explained by the regression.

Table 10--*Mean decay percentages in western hemlock in southeast Alaska by position of external indicator and geographic area*

Position of external indicator	Ketchikan		Petersburg		Sitka		Juneau	
	Number	*Percentage*	*Number*	*Percentage*	*Number*	*Percentage*	*Number*	*Percentage*
Cubic-foot decay:								
0 None	81	1.2	112	3.2	70	4.4	81	8.7
1 Above the first 32-foot log	7	5.0	11	8.7	5	15.4	11	22.5
2 On the first 32-foot log	17	10.3	33	14.2	18	20.3	43	23.2
3 Both on and above the first 32-foot log	6	14.4	19	25.2	4	70.7	14	43.8
Board-foot decay:[1/]								
0 None	81	3.0	112	7.7	70	10.7	81	21.8
1 Above the first 32-foot log	7	8.9	11	23.5	5	27.2	11	53.0
2 On the first 32-foot log	17	30.1	33	31.0	18	45.6	43	47.6
3 Both on and above the first 32-foot log	6	30.5	19	55.6	4	99.0	14	84.6

[1/] Scribner rule.

Hemlock percent board-foot decay

$$Y = 0.91 + 18.79x_1 + 26.37x_2 + 53.78x_3 + 5.41x_4 + 12.66x_5 + 22.47x_6$$

$$R^2 = 0.35$$

For spruce the best solution was simply to use the mean decay percentages by position of external indicator (table 2).

Decay percentages were significantly related to tree diameter for spruce and hemlock trees without indicators. However, the relationships were weak, accounting for less than 10 percent of the variation. Also solutions of the equation gave negative values for small diameter trees in the 12- to 14-inch class. Therefore these equations will not be presented.

Application of Results

Estimation of decay in standing hemlock and spruce lacks the precision that most timber cruisers would like. Although decay factors have been applied to standing trees in southeast Alaska for almost 20 years, there is no guarantee they will give unbiased estimates when applied to localized timber sales (see footnote 2). They are mostly appropriate for large inventories where it is not possible to do destructive sampling and where decay percentages tend to average out.

Reanalysis of Kimmey's (1956) basic data along with data collected here suggests that complex decay prediction equations are unnecessary.

Most equations account for little of the total variation and are biased. Although crude, it is much safer to use general class means. Then users are not misled into thinking the decay factors are better than they really are.

If timber cruisers are willing to risk the accuracy of their cruises by continuing to use standing-tree decay factors, then values given for hemlock in table 1 and for spruce in table 2 are recommended. These are simpler to apply than previously used Kimmey factors (1956), as tree diameter need not be known.

The most easily applied regression relationships for spruce are between decay percentage and location of external indicators. Position of external indicators and geographic area are needed to estimate decay percentages in hemlock. The four recognized geographic areas are Ketchikan, Petersburg, Sitka, and Juneau (fig. 1). Too few hemlock were sampled at Yakutat, and most were sound, so it is recommended that the mean values from table 9 be used for hemlock at Yakutat.

Users of the tables are also cautioned that for safety reasons obvious cull trees were not sampled in this study. Therefore, the values in tables 1 and 2 should not be applied to obvious culls in the field. Instead the trees should be given an indicator code 4, meaning complete cull.

There are at least two alternatives to using decay factors for estimating decay in standing trees. One is to rely on information from felled trees collected from nearby logging operations. Such information could be used to develop local decay factors. Another is to use fall, buck, and scale cruising (Johnson and Hartman 1972). Fall, buck, and scale cruising is being used on some sales in Alaska. Interest in its use is growing, as there is no suitable alternative but to section defective timber if reliable net volumes and values are to be estimated.

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Farr, Wilbur A., Vernon J. LaBau, and Thomas H. Laurent
1976. Estimation of decay in old-growth western hemlock and Sitka spruce in southeast Alaska. USDA For. Serv. Res. Pap. PNW-204, 24 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Trees on sixty seven 1/5th-acre plots were dissected so that a method could be developed for making unbiased estimates of decay in western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) on commercial forest land in southeast Alaska. Decay in both species was related to many variables, but relationships were weak. For hemlock, decay was best related to position of external indicators and to geographic location; decay in hemlock increased to the north. For spruce, the most useful predictor of decay was position of external indicators. These derived decay factors are useful for large-scale inventories; their reliability cannot be guaranteed on local timber sales.

KEYWORDS: Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*, decay (-log quality.

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USDA Forest Service Research Paper PNW-2
19

Determination of Skyline Load Capability with a Programable Pocket Calculator

FEB 19 1977

Ward W. Carson

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE
PORTLAND, OREGON

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DETERMINATION OF SKYLINE LOAD CAPABILITY WITH A PROGRAMABLE POCKET CALCULATOR

Reference Abstract

Carson, Ward W.
1976. Determination of skyline load capability with a programable pocket calculator. USDA For. Serv. Res. Pap. PNW-205, 11 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

For planning purposes, logging engineers need tools and methods to determine the load-carrying capability of skyline cable systems. Both computerized and hand computation methods are available for these determinations; however, no approach has been reported that could be programed onto the pocket-size computers available. This paper presents a method that will determine the load capability of a running or standing skyline on a programable pocket-size calculator.

KEYWORDS: Skyline logging, computation, computer programs.

RESEARCH SUMMARY

Research Paper PNW-205

1976

The trend toward more intensive advance planning of logging activities has definitely been established in recent years, particularly for cable logging operations. Logging specialists and forest engineers now commonly investigate the relationship between cable tensions, ground profile shapes, anchoring geometries, and anticipated log loads before actual field operations. The primary objective is to establish the workability of a proposed operation before actual logging begins.

The nature of this advance planning is inherently computational. For skylines, the relationship between tensions, loads, and geometries can be determined; but a great deal of numerical manipulation is involved. To make the exercise most practical, a computer is required.

The degree of practicability associated with performing the computations necessary for planning skyline logging depends on the availability and cost of the computer. The geographically dispersed nature of forest operations makes the large central computer impractical for most situations because of inaccessibility or cost. The introduction of inexpensive,

pocket-size, programable calculators has, however, changed this situation. These computers are readily available and can perform many of the calculations required for advance planning.

This paper presents the mathematical expressions that make possible determination of the relationship between tensions, geometry, and loads for running and standing skylines. The expressions are condensed to a degree that allow them to be programed on a pocket-size calculator. Approximations are entailed; however, the error associated with them was negligible and is discussed. The derivations presented have been the basis for several computer programs now available on pocket-size calculators.

Introduction

An important step in the process of examining the feasibility of a proposed skyline logging operation is the determination of the load-carrying capability of the skyline equipment. This capability is a function of the equipment size, the anchoring arrangement, and the amount of deflection allowed by the terrain over which the skyline is intended to operate. Determination of the load-carrying capability presents a computational problem to which considerable attention has been devoted, with the result that logging engineers have available several methods for solution. These methods fall into the general categories of (a) handbook methods (*6*, *7*) which use a "chain-and-board" physical analogy and a tabulated set of cable tension and geometry characteristics to determine load-carrying capabilities, and (b) computer methods (*1*, *4*, *5*) which use a mathematical approach.

This paper presents another computer method for determination of skyline capabilities. The approach is conceptually the same as the computer solutions reported previously; however, whereas the early methods required large or at least desk-top computers, this solution can be accomplished on a programable pocket calculator. Some accuracy of the mathematical description has had to be sacrificed; however, comparisons with other available methods have shown the accuracy of the calculator results to be adequate for a wide range of practical situations.

The purpose of this paper is to show the mathematics and assumptions which were necessary to put the solution for skyline load-carrying capability on a hand-held computer. A Hewlett-Packard 65[1/] was used; this computer is capable of executing 100 programed steps and has 9 addressable storage registers. Two programs have been prepared and are discussed in this paper: (a) a solution for the load-carrying capability of a standing skyline shown in figure 1 and (b) a solution for the load-carrying capability of a running skyline shown in figure 2.

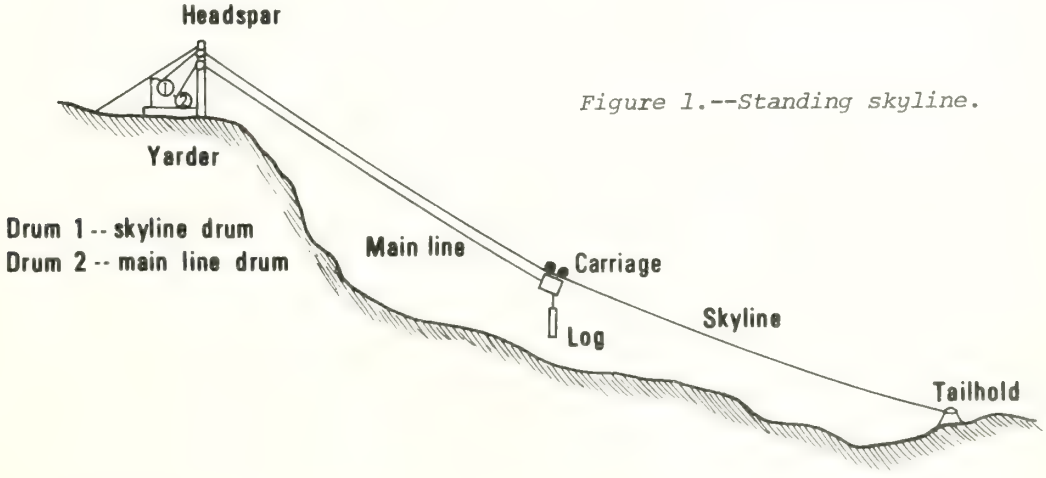

Figure 1.--Standing skyline.

[1/] Mention of products or companies by name does not constitute an endorsement by the U.S. Department of Agriculture.

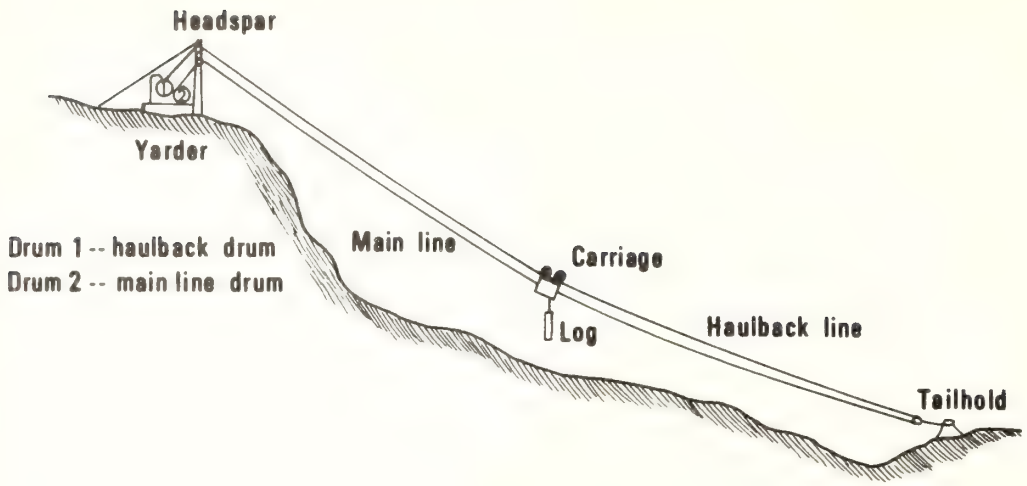

Figure 2.--Running skyline.

BACKGROUND

Analysis of the relationship between tensions, loads, deflections, and line lengths for a skyline system will yield mathematical equations in terms of the hyperbolic functions which describe a catenary curve. Solution of equations will relate the physical variables of the system. However, the determination of these solutions is not trivial; and if computers are to be used, a large computing facility is required. If one wishes to avoid the large computers and would prefer to use a desk-top computer or the programable pocket computer, then the complexity of the mathematical description of the skyline systems must be simplified. This is accomplished by introducting assumptions which simplify but limit the applicability of the results.

This paper discusses the analysis of two skyline systems. The assumptions and subsequent limitations are implicit in this discussion and should be understood by anyone who intends to apply the results of this solution.

The Problem Description

In this paper, mathematical equations are derived to express the gross payload capability, W_G, of a standing or running skyline as a function of the cable systems geometry which is described by

L, the span between anchor points,

h, the elevation difference between anchor points,

d, the horizontal distance from the left anchor to the carriage,

and y, the elevation difference from the left anchor point measured positive down to the point where the carriage rests on the skyline (or haulback);

and the line weights related to

ω_1, the weight per unit length of the skyline

and ω_3, the weight per unit length of the main line, or for the running skyline, the main line-operating line combination;

and T_A, the operating tension of the systems which are given to exist at the left anchor in the skyline of the standing configuration and in the haulback of the running skyline system.

In the computer programs based on these mathematical descriptions, the specified values are then L, h, d, y, ω_1, ω_3, and T_A; and the expected result is W_G.

Mathematical Description

Carson and Mann (*2*, *3*) discussed the mathematical description necessary to determine load-carrying capability for the standing and running skylines, respectively. Recognizing the difficulties associated with the catenary description of these cable systems, the authors discussed an approximate approach as the force balance formulation. This approach will be used here also.

TENSIONS

Consider the free body diagrams of the standing and running skyline cable configurations as depicted in figures 3 and 4, respectively. For

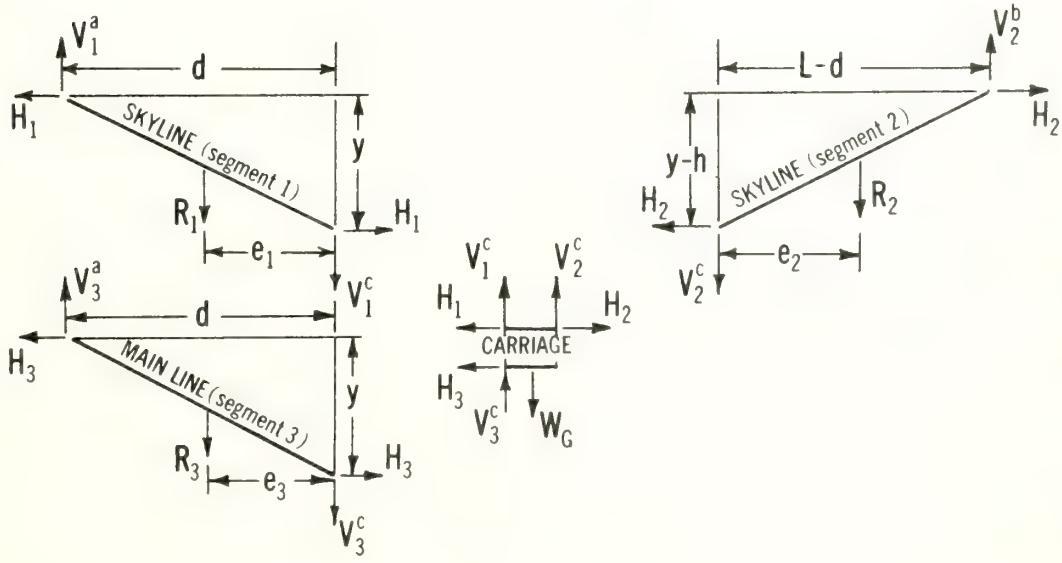

Figure 3.--Free body diagram for standing skyline.

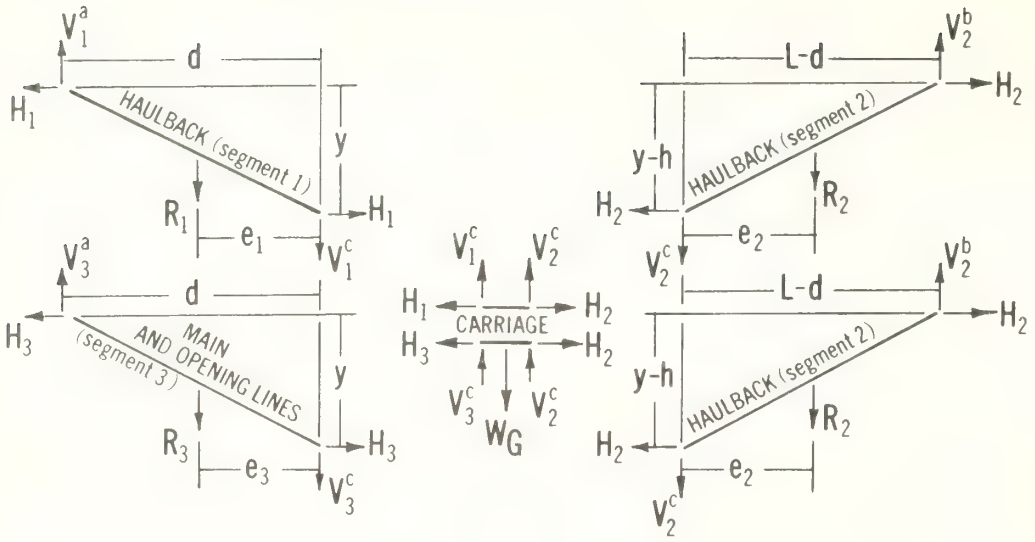

Figure 4.--Free body diagram for running skyline.

both these systems, one can express the horizontal component of tension in line segment 2, H_2, in terms of the known geometric quantities L, h, d, and y; the skyline or haulback tension, T_A, and the line weight per unit length, ω_1. This is accomplished by first using a catenary relationship which states that the tension in the skyline (or haulback) at the carriage is equal to the tension at the headspar minus the product $\omega_1 y$. This and the fact that the tension in this support line is the same on each side of the carriage support sheave provide the expression

$$(T_A-\omega_1 y)^2=(V_2^c)^2+(H_2)^2. \tag{1}$$

The vertical and horizontal components in this expression are related to the line weight and shape of the cable segment. The relationship is revealed in the moment balance

$$V_2^c(L-d)=H_2(y-h)-R_2(L-d-e_2). \tag{2}$$

Combining these, one gets the quadratic equation

$$H_2^2(1+t_3^2)-2H_2R_2t_3\ (1-t_4)+R_2^2(1-t_4)^2-(T_A-\omega_1 y)^2=0; \tag{3}$$

where $$t_3=\frac{y-h}{L-d}\ ,$$

and $$t_4=\frac{e_2}{L-d}\ .$$

V and H are force components in the lines; R is the force component resulting from line weight, and e indicates the moment arm associated with this force. All these terms are defined as shown in figures 3 and 4.

LINE WEIGHTS AND MOMENT ARMS

An assumption which simplifies the mathematics of this description substantially involves the line weights and moment arms of the line segments which depend on the physical shape of each segment, a catenary in reality, and the line weight per unit length:

(a) the line weight is equal approximately to the product of the weight per unit length and the chord length. For the segments in these systems, the weights would be expressed as

$$R_1=\omega_1\left(d^2+y^2\right)^{1/2}; \tag{4}$$

$$R_2=\omega_1\left(\left(L-d\right)^2+\left(y-h\right)^2\right)^{1/2}; \tag{5}$$

and

$$R_3=\omega_3\left(d^2+y^2\right)^{1/2}. \tag{6}$$

In keeping with this assumption, the second simplification is to assume:

(b) the moment arm for the weight of each segment is at the middle of its span. This provides

$$e_1=e_3=1/2d; \tag{7}$$

and

$$e_2=1/2\left(L-d\right). \tag{8}$$

The effect of these assumptions on accuracy of the solution for the running skyline was discussed by Carson and Mann (*3*). The results of a description with these assumptions, such as the one used here, approximate the catenary solution to within a fraction of a percent when the lines are taut. Cables with low tensions will sag and adopt a catenary shape whose length is substantially longer than the chord length. In such cases error will result, the magnitude being proportional to the amount of sag; however, in most cases the cables will be stressed to a maximum working value to carry the largest loads possible. With these conditions, the results of the present analysis are accurate. Nevertheless, those who use these results should keep this limitation in mind.

GROSS PAYLOAD

With the simplified line weight and moment arm expressions of the previous section, the quadratic solution for H_2 can be reduced to:

$$H_2=\frac{\omega_1(L-d)}{2(1+t_3^2)^{1/2}}\left\{t_3+\left[4\left(\frac{T_A}{\omega_1(L-d)}-\frac{y}{L-d}\right)^2-1\right]^{1/2}\right\}. \tag{9}$$

This holds for both standing and running skyline configurations.

The load-carrying capability of each configuration can be related to this component of tension by noting the vertical force balance at the carriage which becomes

$$W_G=V_1^c+V_2^c+V_3^c \tag{10}$$

for the standing skyline and

$$W_G=V_1^c+2V_2^c+V_3^c \tag{11}$$

for the running skyline. The vertical components of tension can be derived from moment balances:

$$V_1^c=H_1t_1-1/2R_1; \tag{12}$$

$$V_2^c=H_2t_3-1/2R_2; \tag{13}$$

and

$$V_3^c=H_3t_1-1/2R_3; \tag{14}$$

where $t_1=y/d$ is introduced here. Substitution of these for equations (10) and (11), respectively, give

$$W_G=(H_1+H_3)t_1+H_2t_3-1/2(R_1+R_2+R_3), \tag{15}$$

and

$$W_G=(H_1+H_3)t_1+2H_2t_3-1/2(R_1+2R_2+R_3). \tag{16}$$

At this point the horizontal force balance is introduced to provide the relationships

$$H_2=H_1+H_3 \tag{17}$$

for the standing skyline and

$$2H_2=H_1+H_3 \tag{18}$$

for the running skyline configuration. Substitution of these provides the

final expressions for the payload; namely,

$$W_G = H_2(t_1 + t_3) - 1/2(R_1 + R_2 + R_3) \tag{19}$$

for the standing skyline and

$$W_G = 2H_2(t_1 + t_3) - 1/2(R_1 + 2R_2 + R_3) \tag{20}$$

for the running skyline configuration. These equations and the computed value of H_2 provide the load-carrying capability as a function of the geometry implied by L, h, d, and y; the line weights derived from ω_1 and ω_3; and the working tension of the skyline (or haulback) specified as T_A.

MAIN LINE TENSION

In both skyline configurations, an amount of main line tension is required to maintain the carriage location. The magnitude can be related to the horizontal component of tension, H_3, which is related to the horizontal components, H_1, and H_2, as expressed in the previous section. As for H_1, a quadratic solution similar to that used for H_2 is available in the form

$$H_1 = \frac{\omega_1 d}{2(1+t_1^2)^{1/2}} \left\{ t_1 + \left[4\left(\frac{T_A}{\omega_1 d} - \frac{y}{d}\right)^2 - 1 \right]^{1/2} \right\} . \tag{21}$$

Therefore, the magnitudes of main line tension and its components follow directly from the equations

$$H_3 = H_2 - H_1 \tag{22}$$

for the standing skyline,

$$H_3 = 2H_2 - H_1 \tag{23}$$

for the running skyline, and

$$V_3^c = H_3 t_1 - 1/2 R_3 \tag{24}$$

and

$$T_3^c = \left((V_3^c)^2 + (H_3)^2 \right)^{1/2} \text{ for both.} \tag{25}$$

The tension at the left anchor can be determined with the catenary relationship

$$T_3^a = T_3^c + \omega_1 y. \tag{26}$$

Error

As noted earlier, the analysis presented here yields accurate results for taut lines only. In the running skyline configuration, this assumption is nearly always satisfied since the tension of the haulback line provides enough force on the carriage to maintain tension in the main line, even for a no-load condition. The same is not true for the standing skyline. Conditions can arise where the tension requirement for the main line is so small that considerable sag will develop. In this section, we examine the error that is induced from low tension in the main line of the standing skyline.

An accurate analysis of the main line, shown in figure 5, would consider the catenary shape it adopts between the left anchor and the carriage. The shape would depend on the horizontal force, H_3, required to hold the carriage in position and would influence the vertical force lifting the carriage, V_3. Such an analysis would yield a relationship between these forces, namely,

$$V_3\Big|_{\text{catenary}} = \frac{\omega_3}{2}\left(y \coth \frac{\omega_3 d}{2H_3} - \bar{s}\right); \qquad (27)$$

where

$$\bar{s} = \left\{ y^2 + \left(\frac{2H_3}{\omega_3} \sinh \frac{\omega_3 d}{2H_3}\right)^2 \right\} 1/2.$$

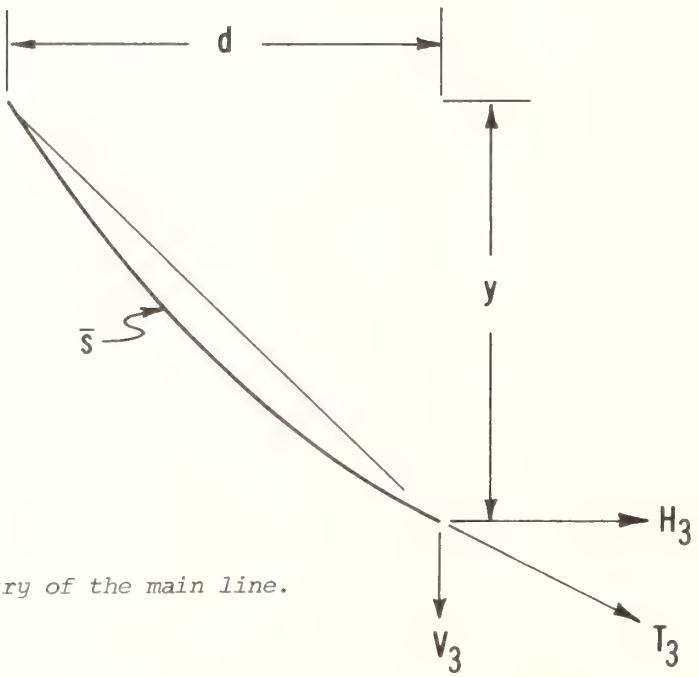

Figure 5.--Geometry of the main line.

By comparison, the approximate analysis developed in this paper yields the relationship

$$V_3 = H_3 \frac{y}{d} - \frac{\omega_3}{2}\left(y^2+d^2\right)^{1/2} . \tag{28}$$

The difference arises from the assumptions made in equations (4), (5), (6), (7), and (8), which ignore the sag of the main line as would be described by the catenary and as would actually exist. It should be apparent that the magnitude of sag, and thus the discrepancy between $V_3)_{\text{catenary}}$ and V_3 that is introduced, is a function of the tautness of the main line, which is in turn a function of the horizontal component of tension, H_3. More specifically, one can recognize that for fixed geometry and line weight per unit length, more sag and thus more discrepancy are caused by lower values of H_3. This can be summarized as an error defined as

$$\text{ERROR} = \frac{V_{3/\omega_3 d})_{\text{catenary}} - V_{3/\omega_3 d}}{H_{3/\omega_3 d}} . \tag{29}$$

This expresses the discrepancy between the approximation for V_3 and that derived from a catenary analysis as a percentage of the horizontal tension required in the main line. All terms have been normalized by the product $\omega_3 d$ to reduce the error to a function of the ratios $\left(y/_d,\ H_{3/\omega_3 d}\right)$ only. A plot of the variation is presented in figure 6.

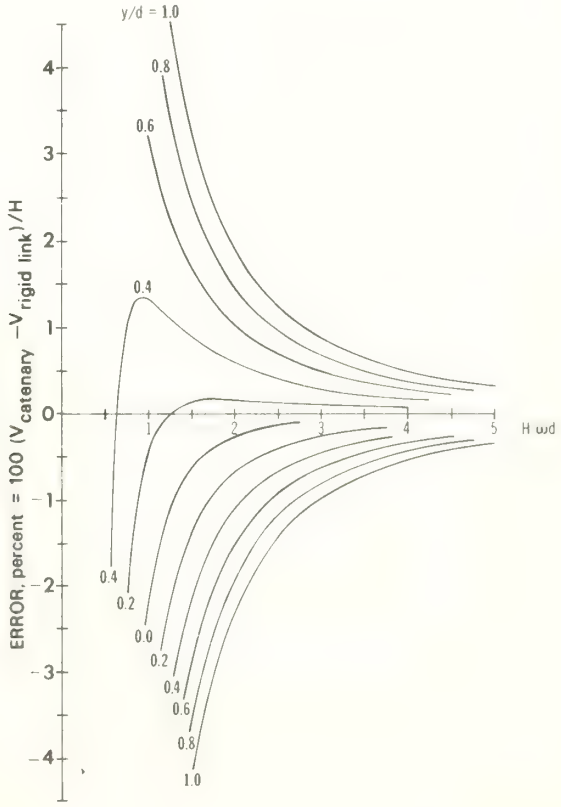

Figure 6.--Error in main line force due to approximate solution.

Therefore, figure 6 provides, for a given carriage location (i.e., y/d), given line weight and horizontal tension requirement (i.e., $H_3/\omega_3 d$), a measure of the error introduced by the approximate analysis presented. Notice that until the ratio $H_3/\omega_3 d$ approaches 2.0, the error for all physically realistic geometries is negligible.

Numerical Example

The computational procedure suggested for a hand-held or small desk-top computer is described best by a numerical example. For the example presented here, we chose a standing skyline anchored with the values

$$L = 2{,}000 \text{ feet } (609.6 \text{ meters}),$$

$$h = 1{,}000 \text{ feet } (304.8 \text{ meters}),$$

$$d = 1{,}400 \text{ feet } (426.7 \text{ meters}),$$

$$y = 850 \text{ feet } (259.1 \text{ meters}),$$

$$\omega_1 = 2.89 \text{ pounds/foot } (42.18 \text{ newtons/meter}),$$

$$\omega_3 = 1.85 \text{ pounds/foot } (27 \text{ newtons/meter}),$$

and

$$T_A = 53{,}300 \text{ pounds } (237\,090 \text{ newtons}).$$

The first step might be a determination of the cable weights involved in the configuration. As indicated in equations (4), (5), and (6), the summation of these weights can be estimated as

$$\left(R_1+R_2+R_3\right) = 9{,}551 \text{ pounds } (42\,485 \text{ newtons}).$$

Equation (9) provides a direct computation of line segment 2, horizontal tension component, as

$$H_2 = 49{,}108.0 \text{ pounds } (218\,443 \text{ newtons}).$$

The computations are completed by substituting into the payload equation (19) which for the standing skyline gives

$$W_G = 12{,}763.2 \text{ pounds } (56\,774 \text{ newtons}).$$

To assess the error which is introduced, the computations are continued, to determine

$$H_3 = 4{,}632.1 \text{ pounds } (20\,605 \text{ newtons})$$

as the horizontal tension required to hold the carriage at d = 1,400 feet (426.7 meters). This implies that

$$\left(\frac{y}{d}\ ,\ \frac{H_3}{\omega_3 d}\right) = (0.607,\ 1.788)$$

which, from figure 6, indicates an error of 1.26 percent. Therefore, a catenary analysis would have altered the load-carrying capability by approximately 58 pounds (258 newtons).

The procedure for determination of a running skyline load capability would be the same except for the variations in the equations which have been noted under "Gross Payload."

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Carson, Ward W.
1976. Determination of skyline load capability with a programable pocket calculator. USDA For. Serv. Res. Pap. PNW-205, 11 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

For planning purposes, logging engineers need tools and methods to determine the load-carrying capability of skyline cable systems. Both computerized and hand computation methods are available for these determinations; however, no approach has been reported that could be programed onto the pocket-size computers available. This paper presents a method that will determine the load capability of a running or standing skyline on a programable pocket-size calculator.

KEYWORDS: Skyline logging, computation, computer programs.

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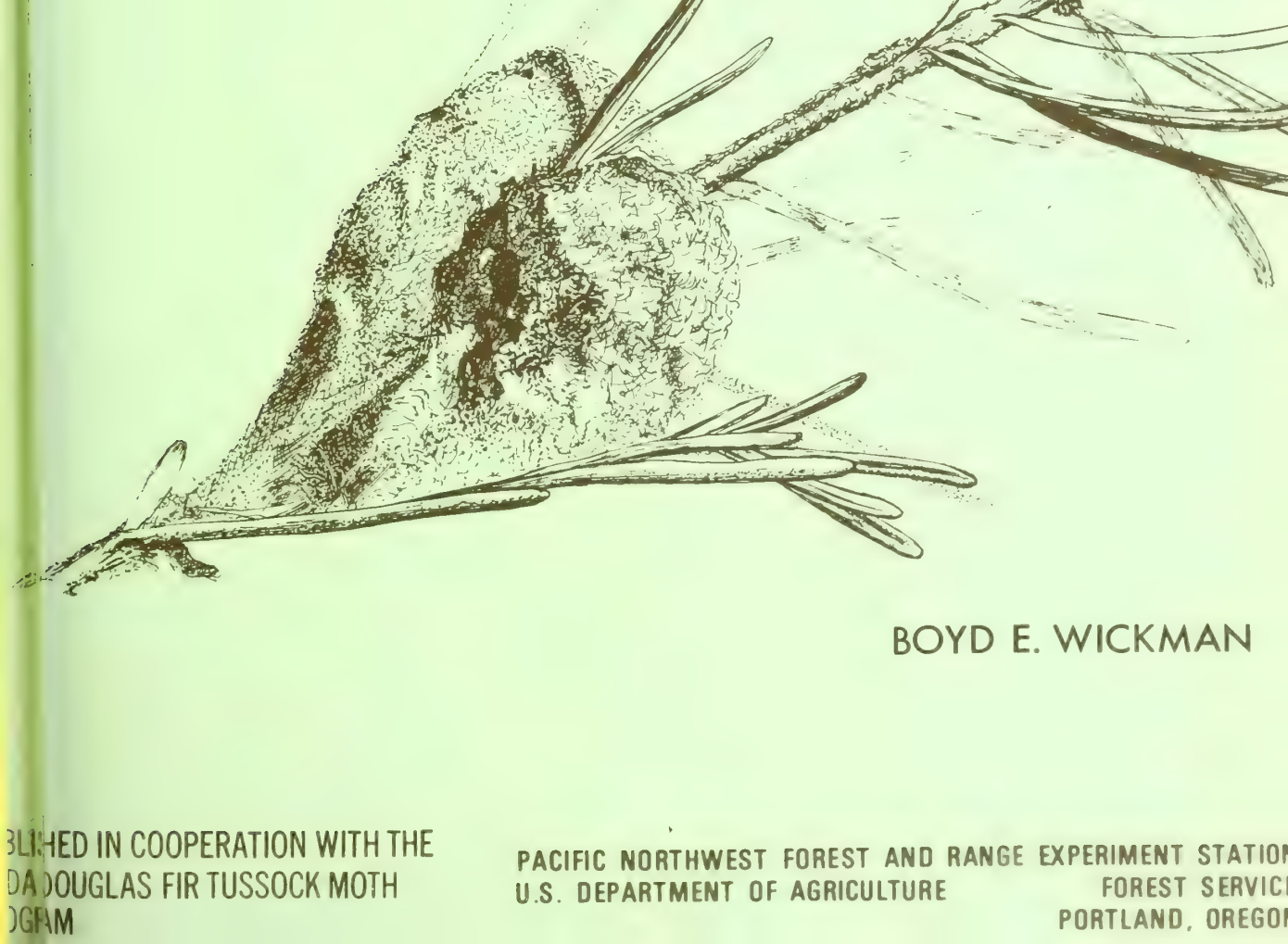
USDA FOREST SERVICE RESEARCH PAPER PNW-206
1976

douglas-fir tussock moth
research & development program

Douglas Fir Tussock Moth Egg Hatch and Larval Development In Relation to Phenology of Grand Fir and Douglas-fir In Northeastern Oregon



BOYD E. WICKMAN

BLISHED IN COOPERATION WITH THE
DA DOUGLAS FIR TUSSOCK MOTH
OGRAM

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

DOUGLAS FIR TUSSOCK MOTH EGG HATCH AND LARVAL DEVELOPMENT IN RELATION TO PHENOLOGY OF GRAND FIR AND DOUGLAS-FIR IN NORTHEASTERN OREGON

Reference Abstract

Wickman, Boyd E.
1976. Douglas fir tussock moth egg hatch and larval development in relation to phenology of grand fir and Douglas-fir in northeastern Oregon. USDA For. Serv. Res. Pap. PNW-206, 14 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Bud burst, shoot elongation, egg hatch, and larval development were studied on six areas in a 1973 infestation in the Blue Mountains. Bud burst and egg hatch were found to be closely related to accumulated degree-days, and peak egg hatch occurred after all buds had burst and shoots were 50 percent or more elongated. Larval development then closely followed shoot elongation. This synchrony of host and insect phenology provides an easily observed field event for monitoring Douglas fir tussock moth development.

KEYWORDS: Douglas fir tussock moth, *Orgyia pseudotsugata*, larval development, phenology, *Abies grandis*, *Pseudotsuga menziesii*.

RESEARCH SUMMARY

Research Paper PNW-206

1976

Information on phenological synchrony was needed in the Blue Mountains of Oregon for two hosts of the tussock moth, grand fir and Douglas-fir, and for comparing the phenological development in two widely separated areas. Therefore, in April 1973 a study was started in the Blue Mountains on six different areas. The study sites were located at various elevations, from 3,200 feet (975 m) to 4,800 feet (1 463 m), and in both pure stands of grand fir and Douglas-fir and mixed stands. Temperature records were maintained on the plots and tree and insect development measured periodically for 3 months.

An earlier study aimed at correlating temperature with development of the Douglas fir tussock moth and white fir, its host in California, showed that bud burst and egg hatch were closely related and the synchrony of host and insect phenology provided an easily observed field event for monitoring Douglas fir tussock moth development (Wickman 1976).

The Oregon study showed that heat unit accumulation was related to elevation with the lowest plot consistently running 5 to 15 days ahead of the higher plots. Bud burst started between 244 and 268 degree-days and proceeded rapidly until 90 percent of bud burst had occurred between 340 and 444 degree-days. Bud development was similar for both tree species except on the lower elevation plot where Douglas-fir bud burst preceded grand fir bud burst by several days. Bud development occurred at slightly lower accumulated degree-days than for white fir in California where first bud burst started between 290 and 356 degree-days and 90 percent occurred between 464 and 535 degree-days.

The relationship of egg hatch to bud burst showed that first egg hatch coincided with 86- to 100-percent bud burst on grand fir and 70- to 97-percent bud burst for Douglas-fir. This is slightly more than the 63- to 86-percent bud burst recorded in California on white fir. More important, all buds had burst and shoots were 75 to 90 percent elongated by the time all larvae had dispersed from the egg masses to new foliage. Measurements and observations of egg hatch revealed that this event contained the most variation. Egg hatch was found to vary at a given location over a 6- to 14-day period.

Shoot elongation was also compared with the predominant larval instar sampled on foliage through the larval development period. In 1973, 90 percent of the shoot growth took place in 29 to 44 days from mid-May until early July. In the first and second instar 85 to 97 percent of the shoot growth had taken place and by the late instars (fourth to sixth) the shoot growth was completed. This synchrony with shoot development assured the larvae of a necessary food supply of new foliage for the early instars.

The findings of this study indicate similar phenological relationships with tussock moth egg hatch and larval development for both white fir in California and grand fir and Douglas-fir in Oregon. Phenological studies suggest that monitoring bud burst in the field is a practical and simpler phenological index than monitoring Douglas fir tussock moth egg hatch. The ability to predict when young larvae first start feeding is extremely important for timing treatment operations, sampling populations, and studying natural enemies. The synchrony of insect development with bud burst seems an obvious and useful index.

The research reported here was financed in part by the USDA Expanded Douglas Fir Tussock Moth Research and Development Program.

INTRODUCTION

The Douglas fir tussock moth (*Orgyia pseudotsugata* (McD.)) is a univoltine insect which seriously defoliates Douglas-fir and true fir over much of the Western United States and Canada (Wickman et al. 1973). Each female deposits up to several hundred eggs in a single mass in late summer or early fall. The masses are most commonly found on or near foliage of the host tree where the eggs overwinter. Egg hatch occurs in late spring or early summer, and emerging larvae feed first on new foliage and then on old foliage if new foliage is depleted. This is a critical portion of the insect's life cycle. Newly hatched larvae must have new growth available for feeding, or mortality by starvation is high and there are other deleterious effects on the population (Mason and Baxter 1970, Beckwith 1976). Many people have noted that egg hatch occurs shortly after bud burst of the host trees. This synchrony assures young larvae a supply of new foliage.

The first attempt to relate the time of egg hatch to ambient air temperature was by Perkins and Dolph (1967). They noted in the 1965 Douglas fir tussock moth infestation near Burns, Oregon, that egg hatch was related to accumulated average air temperatures. They concluded that "whenever the daily average cumulative air temperature nears 50 °F, Douglas fir tussock moth eggs are likely to start hatching."

A study aimed at correlating temperature with development of the Douglas fir tussock moth and the foliage of white fir (*Abies concolor* (Gord. and Glend.) Lindl.), its host in California, was conducted in 1972 on the Eldorado National Forest near Placerville, California (Wickman 1976). There bud burst and egg hatch were closely related to accumulated degree-days, with peak egg hatch occurring when 80 to 95 percent of the buds had burst. Larval development then closely followed shoot elongation. This synchrony of host and insect phenology provided an easily observed field event for monitoring Douglas fir tussock moth development and determined the schedule for population sampling.

In 1973, life table studies of Douglas fir tussock moth in Oregon (Mason, in press) showed the need for the same kind of information on phenological synchrony obtained in California. Therefore, a study was started in April 1973 in the Blue Mountains of northeastern Oregon to see if the phenological synchrony found in California in 1972 was similar for Oregon in 1973. This would indicate whether results from phenological studies can be extrapolated from one area to another. There were some differences between the California situation and this study: (1) There are two preferred host species in northeastern Oregon, grand fir (*Abies grandis* (Dougl.) Lindl.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco); (2) Mason and I were sampling population densities at least 10 times larger than in California; (3) many of the study trees had suffered heavy defoliaton in 1972 and by spring 1973 had very sparse foliage in the upper crown. I did not know what effect this might have on bud burst and shoot growth.

A second objective was to establish, for the Blue Mountains of Oregon, a reliable system for predicting Douglas fir tussock moth development based on the easily observed phenology of host tree foliage.

METHODS

The methods were similar to those used in the California phenology study (Wickman 1976) except large trees were not sampled at midcrown with pole pruners to determine bud burst.

Location of Study Areas

Six study sites were located at various elevations and exposures:

1. Frizzel Creek--3,200-foot (975-m) elevation, eastern exposure (flat), open-grown mixed grand fir--Douglas-fir second-growth stand.

2. East Mt. Emily Road--4,000-foot (1 219-m) elevation, eastern exposure, steep slope, dense grand fir second-growth stand. (Temperature records incomplete because of thermograph malfunction and observations incomplete because of logging disruption.)

3. Meacham (U.S. Weather Service Station)--4,050-foot (1 234-m) elevation, northwestern exposure (slight draw), dense grand fir young sawtimber stand.

4. Y Ridge--4,150-foot (1 265-m) elevation, western exposure (flat), open-grown mixed Douglas-fir--grand fir second-growth stand.

5. East Mt. Emily Road--4,650-foot (1 417-m) elevation, eastern exposure, moderate slope, grand fir with some Douglas-fir old-growth stand. (Records incomplete because logging activity prevented regular access.)

6. Drumhill Ridge--4,800-foot (1 463-m) elevation, slight eastern exposure (ridgetop), open-grown mixed grand fir--Douglas-fir old-growth stand. (Temperature records incomplete because of thermograph malfunction.)

Only areas 1, 3, and 4 had complete temperature, egg hatch, and foliage measurements. The other three areas produced only partial data.

A several-acre plot composed of 10 open-grown trees 10 to 15 feet (3 to 5 m) tall was marked in each area. Each area except 2 and 3, which were all grand fir, contained five grand fir and five Douglas-fir trees.

Temperature Records

Air temperature recording stations were set up on each study plot. Each station contained a 7-day recording hygrothermograph and a maximum-minimum thermometer placed in a standard weather instrument shelter. The Meacham U.S. Weather Service Station, located 200 feet (61 m) from the study trees provided daily temperature records for that plot and a check for aberrations on other plots. A threshold temperature of 42 °F (7 °C) was used to keep this study comparable with the California measurements (Wickman 1976). The heat units were accumulated by summing daily averages. One degree of the mean daily temperature above the 42 °F threshold is known as a degree-day. Accumulated degree-days were then calculated for each plot. If degree-day calculation resulted in a negative value it was considered zero, since growth can only be arrested, not reversed.

Foliage Sampling

Each study tree had four tagged primary branches on the four cardinal sides of the midcrown. Seven days after the average daily temperature reached 42 °F one terminal bud on each branch was marked, measured, and examined at 3-day intervals. After the 14th day, buds were examined daily until first bud burst. After bud burst, the new shoot on each branch was measured to the nearest 0.25 inch (0.6 cm) every 3 days during egg hatch and dispersal of larvae off the egg masses. Additional weekly measurements were made until shoot growth was complete.

For the purposes of this study, bud burst occurred whenever individual needles were protruding from the transparent sheath encasing expanding buds and thus available to the young larvae for feeding.

Egg Mass Examinations and Larval Samples

Four egg masses per tree on five trees per plot were marked and examined every other day until first egg hatch. Through the egg hatch and dispersal period, the number of larvae resting on the egg masses was counted daily with the aid of a magnifying glass to obtain a hatch index. This was continued until all the larvae left the egg masses.

Feeding larvae were sampled from the midcrown foliage of 15 nearby trees at Y Ridge and Drumhill Ridge every 2 weeks until pupation; a standard sampling technique was used (Mason 1970). The predominant larval instar at a given sample date was then compared with average shoot growth.

RESULTS AND DISCUSSION

To demonstrate a relationship between development of the tussock moth and the phenology of its hosts, several steps were taken with the field data. Heat unit accumulation by date was compared between areas to point out elevational differences; then degree-days were compared with bud burst at each study site. Egg hatch was monitored, quantified, and related to degree-days and bud burst; and, finally, shoot elongation was compared with larval development. The following sections give the results of each of these portions of the study and discuss additional observations and problems encountered.

Degree-days and Bud Burst

Heat unit accumulation was related to elevation with the lowest plot, Frizzel Creek, consistently running 5 to 15 days ahead of the higher plots, Y Ridge and Meacham (fig. 1). Figure 1 also shows that Y Ridge and Meacham had similar heat unit accumulations. This is expected since there is only a 100-foot (30-m) elevation difference between the two localities, but the close fit indicates that the thermograph recordings, at this location at least, were comparable to a U.S. Weather Service Station with more sophisticated automated equipment. Unfortunately, two of the five field thermographs developed serious malfunctions during the season.

starting at the lowest elevation (Frizzel Creek, 3,200 feet (975 m)) and proceeding to the highest (Drumhill Ridge, 4,800 feet (1 463 m)). The only exception was the Meacham plot (4,050 feet (1 234 m)) where development was similar to the highest plot. This anomaly was most likely due to plot location at Meacham. The trees nearest the weather station were about 200 feet (61 m) away in a slight draw which proved cooler than the site of the U.S. Weather Service instruments. The lower temperatures at the plot were confirmed by several spot checks with a mercury thermometer. This points out the difficulty of selecting broadly representative sites for studying phenological events; care must be taken not to extrapolate temperatures to areas very distant from the study sites. Hopkin's Law (1918) regarding delay in development with increased elevation is a well-documented generalization, even in the Blue Mountains (Wagg 1958); however, exceptions do exist, usually because of effects of local physiography on heat unit development.

Figure 2B indicates an interesting characteristic of Douglas-fir bud burst noted during this study. In the lowest elevation plot at Frizzel Creek, Douglas-fir consistently flushed new foliage before grand fir. The reverse was true on all the other areas, with Douglas-fir bud burst lagging several days behind grand fir. The situation at Frizzel Creek may have been influenced by the eastern exposure slowing development of grand fir.

Bud burst often occurred first on the most open-grown trees, the upper crown of large trees, and sometimes on the south aspect of sample trees, but there was no substantial difference by aspect on the sample trees. This agrees with findings in the California study (Wickman 1976).

Percent bud burst plotted against accumulated degree-days for grand fir and Douglas-fir at Frizzel Creek, Y Ridge, and Meacham (only grand fir) is shown in figure 3. Bud burst started between 244 and 268 degree-days and proceeded rapidly until 90 percent of the bud burst had occurred between 340 and 386 degree-days (except for Douglas-fir at Y Ridge which reached the 90-percent bud burst point at 444 degree-days). Bud development occurred at lower accumulated degree-days than for white fir in California. There, first bud burst started between 290 and 356 degree-days and 90 percent occurred between 464 and 535 degree-days (Wickman 1976). Some of this difference might be explained by the effects of unseasonably warm spring weather in Oregon in 1973 versus the unseasonably cool spring in California in 1972. And since the relationship of bud development with temperature is curvilinear, the onset of bud burst increases with the rate of temperature accumulation. As California was cooler, there was a slower rate of development for the same accumulated temperature.

Degree-days, Bud Burst, and Egg Hatch

The relationship of egg hatch to accumulated degree-days and bud burst must be demonstrated to ultimately use bud burst alone as a field indicator of egg hatch. The first step is shown in figure 4; average number of larvae per egg mass (counted on the egg mass) is plotted by accumulated degree-days for Frizzel Creek, Y Ridge, and Meacham. The Y Ridge curve shows an extended period of egg hatch which I believe was

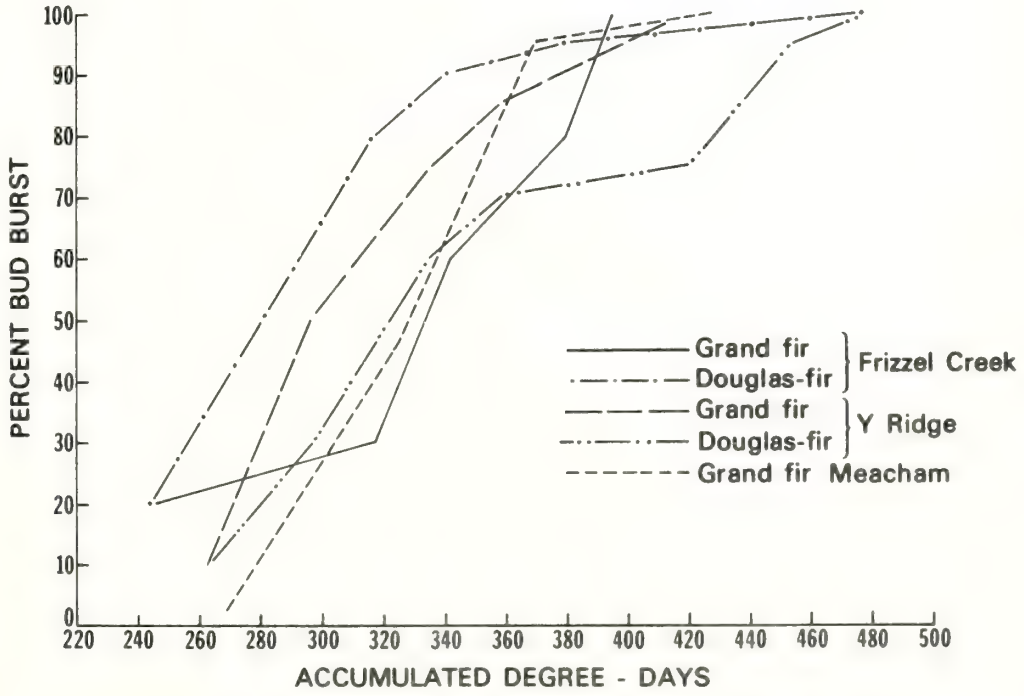


Figure 3.--Accumulated degree-days and percent bud burst by grand fir and Douglas-fir, phenology plots, 1973.

due to additional exposure of egg masses to solar radiation. Eight egg masses were located on trees in large openings and exposed to longer periods of radiation. Masses on those trees hatched several days earlier than on trees in the fringe of the stand canopy.

Comparison of figure 4 with figure 5 shows peak egg hatch occurred 4 days after first egg hatch at Frizzel Creek, 10 days after first hatch at Meacham, and one peak 3 days after first hatch and a second peak 10 days later at Y Ridge. Except for Frizzel Creek, this period is slightly longer than found in California, but the time from peak egg hatch to complete dispersal off the egg masses was shorter than in California (7 to 10 days); at Frizzel Creek it was 4 days, Meacham 5 days, and Y Ridge 2 days (for the second peak).

The accumulated degree-days plotted against percent bud burst and egg hatch are also illustrated by figure 5. These graphs point out that on our study areas in 1973, first egg hatch coincided with 86- to 100-percent bud burst on grand fir and 70- to 97-percent bud burst for Douglas-fir. This is slightly more than the 63- to 86-percent bud burst recorded in California on white fir in 1972 (Wickman 1976). More important, all buds

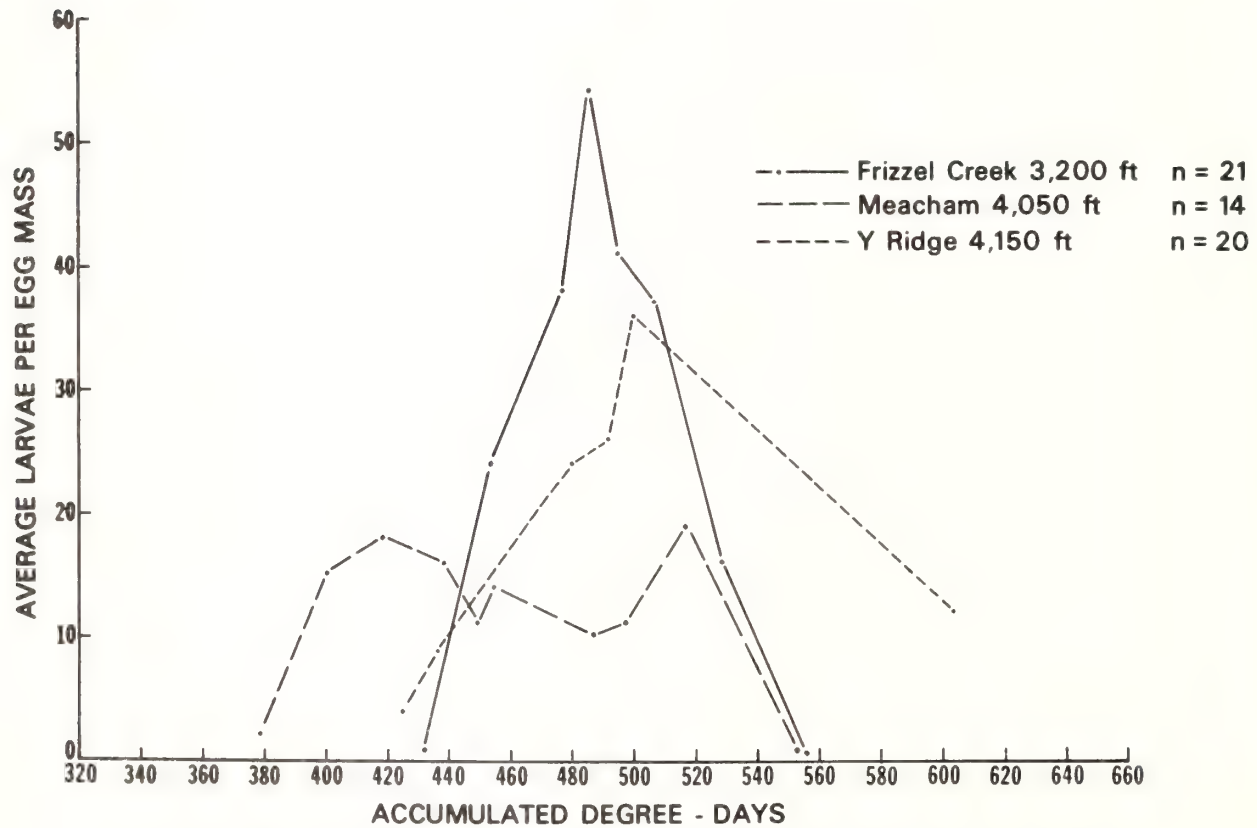


Figure 4.--Average number of larvae per egg mass (counted on the egg mass), phenology plots, 1973.

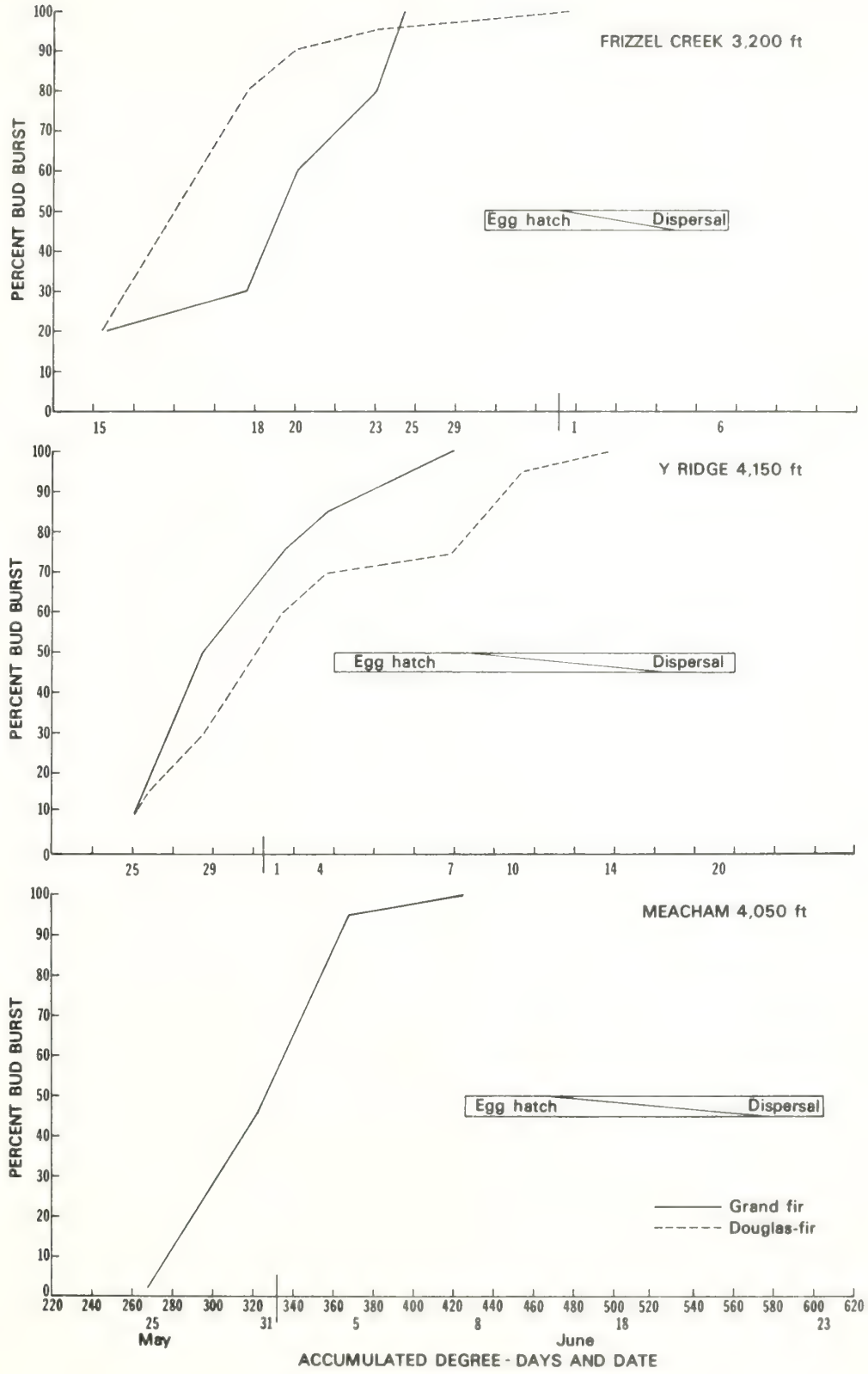


Figure 5.--Accumulated degree-days, percent bud burst, and egg hatch and dispersal for three phenology plots, 1973.

had burst and shoots were 85 to 90 percent elongated by the time all larvae had dispersed from the egg masses to new foliage and were vigorously feeding.

Measurements and observations of egg hatch revealed that this event contained the most variation. Apparently, eggs in the tops of large exposed trees hatched first (buds in the tops of these trees also burst earlier). The dispersal of larvae from these trees resulted in long silken threads, easily seen when looking toward the sun, streaming from the tops of trees. Because larvae remain on the egg masses for several days before dispersing, first egg hatch probably preceded visual evidence of silk threads in tree tops by about 3 days. Egg hatch lower in the crown (and this is where most egg masses are located in heavily defoliated trees) coincided well with hatch on tagged masses and started about the time silk was seen. Egg masses in the lower crowns of trees in dense stands with light defoliation were the last to hatch, and in several locations hatch occurred 3 to 4 days after hatch at midcrown. This means that egg hatch can occur at a given locality over a 6- to 14-day period, and, when egg masses are tagged for observation of hatch, the amount of exposure to solar radiation must be considered.

Also, in the declining phase of an outbreak some egg masses produce few or no larvae. If these egg masses are tagged for observation, they will obviously result in some miscalculations, especially when the sample size is small.

Shoot Elongation and Larval Development

Comparison of shoot elongation with the predominant larval instar sampled on foliage through the larval development period was possible for only two of the six study sites (fig. 6). The shoot growth was measured on three additional study plots not sampled for larvae and showed a similar configuration and time scale. In this 1973 study, 90 percent or more of the shoot growth took place in 29 to 44 days from mid-May until early July. This was a longer time period than in the California study (about 32 days), but there was only a 600-foot (183-m) elevation difference in California between plots compared with 1,600 feet (488 m) in Oregon.

In 1973 shoot growth was 90 percent or more complete by the second instar. In California in 1972 only 50 percent of the shoot growth had taken place during the third and fourth larval instars (Wickman 1976). In Oregon, summer 1973 was particularly warm and dry, and rapid shoot growth by the time of second instar development insured the larvae the maximum food supply possible. This, in turn, resulted in heavy feeding on almost all available new growth by the very dense larvae populations on our plots. Thus the unusually warm weather hastened shoot growth but probably also stimulated more rapid larval feeding. This heavy larval feeding in Oregon resulted in reduced total length shoot growth, and also could have ended growth earlier in the season, explaining the differences between Oregon and California. The total end of season (1973) average shoot length at Y Ridge was 1.02 inches (2.59 cm) for grand fir and 1.17 inches (2.97 cm) for Douglas-fir; at Drumhill Ridge it was 1.35 inches (3.43 cm) for grand fir and 1.40 inches (3.56 cm) for Douglas-fir.

Aspect caused no appreciable difference in shoot growth, either by development rate or total length. This is similar to the findings of Morris et al. (1956) on balsam fir in New Brunswick and Wickman (1976) on white fir in California.

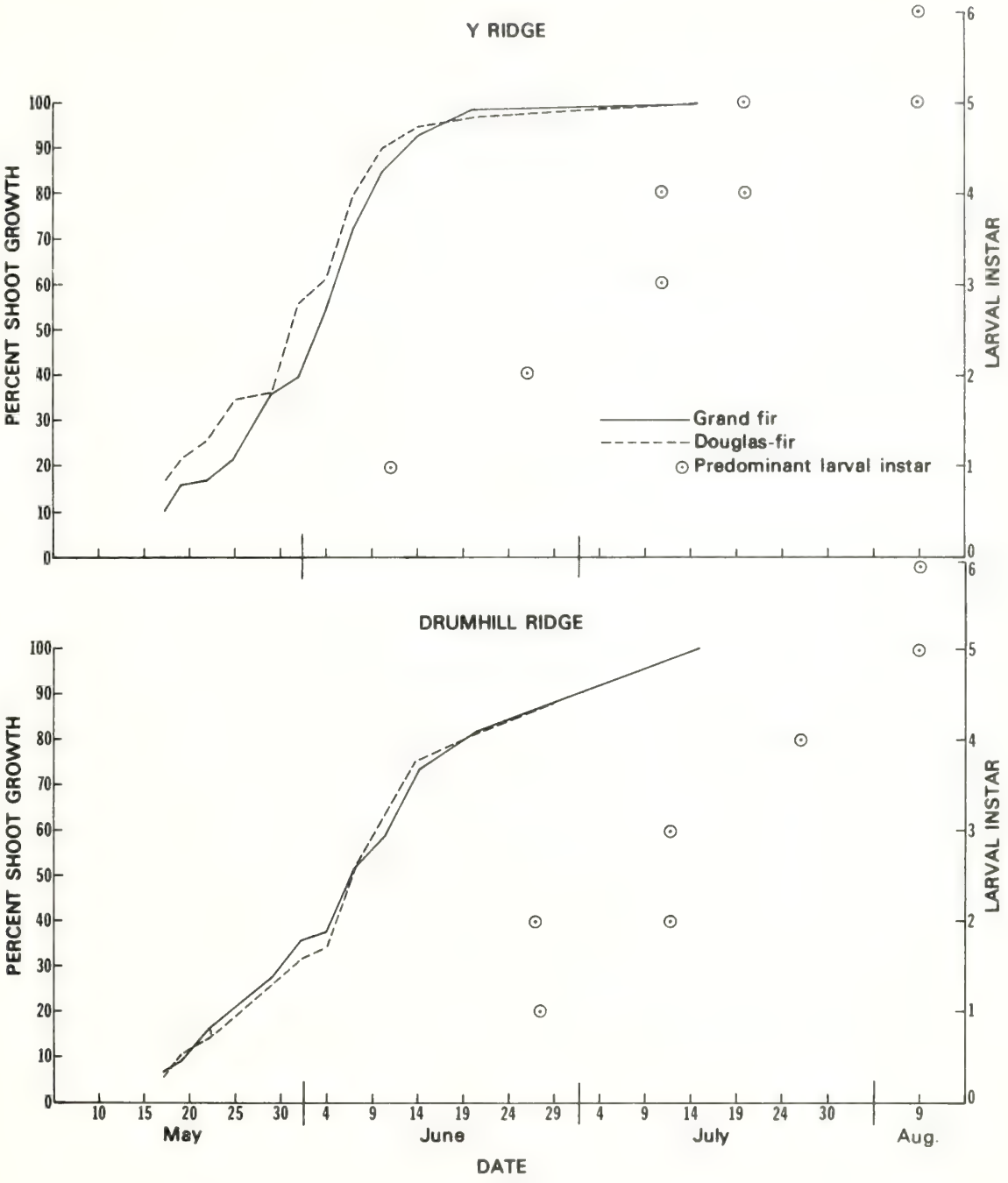


Figure 6.--Relationship of shoot growth and larval development on two phenology plots, 1973.

CONCLUSIONS

The findings of this study indicate similar phenological relationships with tussock moth egg hatch and larval development for both white fir in California (Wickman 1976) and grand fir and Douglas-fir in the Blue Mountains of northeastern Oregon. The results are also similar to the phenological relationships of western spruce budworm larval development with these two hosts in the Blue Mountains of Oregon (Wagg 1958). In 1974 we did some remeasurements of the plots at Y Ridge and Drumhill Ridge plus several new areas to substantiate the 1973 data. The configuration of bud burst and shoot growth curves was similar, only skewed to a later date because of the cool, wet spring and early summer of 1974. There were so few egg masses available for study on our plot areas in 1974 that we were not able to duplicate the egg hatch-bud burst measurements.

An easily used and apparently reliable system for predicting tussock moth egg hatch and dispersal of larvae to new foliage was developed for the Blue Mountains of Oregon. It is based on the phenology of host tree foliage. Because of variation within trees and stands, a general schedule for estimating egg hatch might be helpful. It must be remembered that the schedule is governed by daily average temperatures, but it can also be influenced by the amount of daily solar radiation. Information from this study indicated that after first bud flush it takes about 10 days before most buds are flushed. At this time egg hatch begins and many shoots are about 25 percent elongated. About 7 days later, egg hatch peaks (there is also dispersal during this period) and dispersal of larvae off the egg masses continues for an additional 5 days. By this time about 50 to 90 percent of the shoot elongation has taken place. Schematically it would look like this (± 1 to 5 days).

Day 1 (first bud flush)——————→day 10 (most buds flushed-egg hatch starts)——————→day 17 (egg hatch peaks)——————→day 22 (larvae dispersing, shoots 50 percent or more elongated)

The most visible indicator for this schedule of events is new foliage development.

Ideally, sampling or treating early instar larvae should be carried out when they are well dispersed in the foliage. This will mean that some feeding damage will have occurred in the upper crowns of larger trees and exposed trees by the early hatching individuals before dispersal is complete.

The several years of phenological studies in California and Oregon do suggest that monitoring bud burst in the field is a practical and simpler phenological index than monitoring Douglas fir tussock moth egg hatch. The ability to predict when young larvae first start feeding is extremely important for timing treatment operations, sampling populations, and studying natural enemies. The synchrony of insect development with bud burst seems an obvious and useful index.

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Bud burst, shoot elongation, egg hatch, and larval development were studied on six areas in a 1973 infestation in the Blue Mountains. Bud burst and egg hatch were found to be closely related to accumulated degree-days, and peak egg hatch occurred after all buds had burst and shoots were 50 percent or more elongated. Larval development then closely followed shoot elongation. This synchrony of host and insect phenology provides an easily observed field event for monitoring Douglas fir tussock moth development.

KEYWORDS: Douglas fir tussock moth, *Orgyia pseudotsugata*, larval development, phenology, *Abies grandis*, *Pseudotsuga menziesii*.

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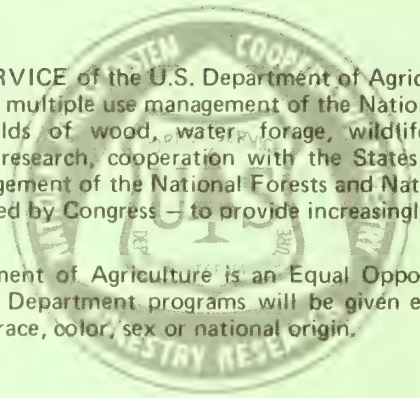

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USDA Forest Service Research Paper PNW-207
1976

cassette tapes or interpretation

by j. alan wagar

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PACIFIC NORTHWEST FOREST and RANGE EXPERIMENT STATION
U.S. Department of Agriculture · Forest Service Portland, Oregon

When this work was done, J. Alan Wagar was leader of the Environmental Interpretation Research Project, formerly maintained by the U.S. Forest Service in cooperation with the College of Forest Resources, University of Washington, Seattle. He is currently leader of the Recreation Research Project maintained by the Forest Service in cooperation with the State University of New York College of Environmental Science and Forestry, Syracuse.

CASSETTE TAPES FOR INTERPRETATION

Reference Abstract

Wagar, J. Alan
1976. Cassette tapes for interpretation. USDA For. Serv. Res. Pap. PNW-207, 20 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Interpretation using portable tape players and cassettes provided significantly greater enjoyment and short-term retention of information on a visitor trail than either trail signs or a trail leaflet. Tape format using questions increased retention of the information so emphasized but at the risk of reducing retention of other information. On-the-ground costs were estimated as between 4 and 9 cents per visitor contact.

KEYWORDS: Recreation, information and education, information media, interpretation, environmental education.

RESEARCH SUMMARY

Research Paper PNW-207

1976

Interpretation using portable tape players and cassette tapes was tested on a nature trail and, to a limited extent, for an interpretive auto tour. Purposes of the tests were (1) to compare the effectiveness of tapes with that of trail signs and leaflets, (2) to compare the effectiveness of taped presentations organized in different ways, and (3) to examine the administrative and logistic problems associated with issuing tape players. Criteria for "effectiveness" were visitor enjoyment and short-term retention of information.

Taped presentations were significantly more effective than either trail signs or a trail leaflet (fig. 1). The sparing use of questions to emphasize key points was found to increase the retention of information so emphasized. For synchronization with attractions, tapes for auto tours need to be keyed to mileage markers or other readily identified features.

If introductory information is given at the beginning of a tape, visitors must have sufficient walking (or driving) distance to proceed at normal speed before passing the first interpretive station before it is discussed on tape.

On-the-ground costs for using cassette tapes and players were estimated at between 4 and 9 cents per visitor contact provided that equipment is offered at an existing facility where personnel already available can handle it. Although requiring recipients to sign a receipt avoided theft or willful damage during the study, procedures probably would need to be developed to recover unreturned equipment, to collect a deposit sufficient to guarantee its return, or both.

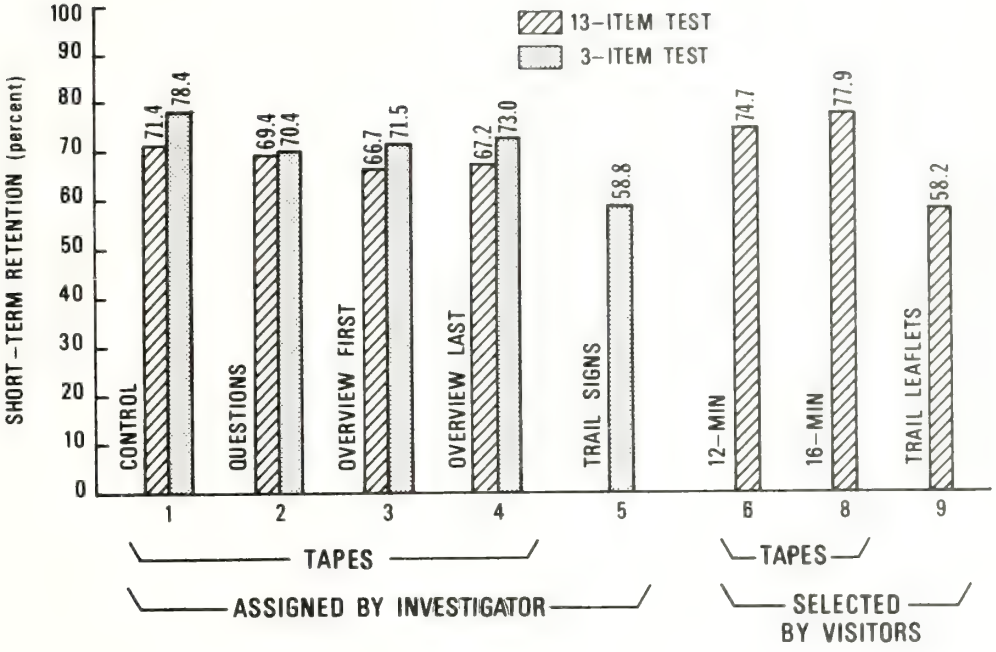

Figure 1.--Average short-term retention of information for the Trail of the Restless Waters, Siuslaw National Forest, Oregon, 1971. Retention for the tapes was significantly greater ($P < 0.01$) than retention for either the trail signs or the trail leaflet.

INTRODUCTION

Cassette tapes and portable tape players are increasingly being used to provide recreationists with information and enjoyment in the places they visit. Recorded walking or auto tours are now available for many of the world's major cities, several National Park Service areas, Niagara Falls, and other attractions. Some of these tapes include over an hour of actual narration.

Previous studies have shown that visitor interest averages greater when information is heard rather than read (Mahaffey 1969, Washburne and Wagar 1972) but offered few conclusions about the amount of information transmitted to and retained by visitors. It seemed likely, however, that recorded messages would permit visitors to absorb substantial amounts of information without looking away from main attractions and with minimal fatigue (Erskine 1964).

To find out if this is true, a study was conducted during the summer of 1971. Purposes of the study were (1) to compare the effectiveness of cassette tapes with that of trail signs and leaflets, (2) to compare the effectiveness of taped presentations structured in four different ways, (3) to obtain some insights on cassette tape auto tours, and (4) to examine the administrative and logistic problems associated with issuing tape players.

Criteria for "effectiveness" were visitor enjoyment and short-term retention of information. Long-term effects of information have been found to be proportional to short-term effects (Cromwell 1955).

AREAS STUDIED

The major part of the study was conducted at the Trail of the Restless Waters at Cape Perpetua, 24 miles north of Florence on the Oregon coast. This half-mile loop trail starts in a forest and then passes through areas of lower vegetation, down along the intertidal zone, and back through the forest to the starting point beside a parking lot (fig. 2)

The trail interprets the forces that have shaped the Oregon coast, including vulcanism, climate and vegetation, tides and wave action, and sea life. A major feature near the beginning of the trail is the Devil's Churn, a wave-cut cleft and cave in a large shelf of basalt.

Most visitors were attracted to the trail by a highway sign reading "Devil's Churn Overlook, 1,000 feet." As a result, many of them had not intended to walk the whole length of the trail. Some people, however, were using this and other trails in conjunction with their visit to the Cape Perpetua Visitor Center approximately half a mile away.

A second location for this study was the scenic Mount Baker Highway in the Mount Baker-Snoqualmie National Forest of northwestern Washington. Late in the summer, a cassette auto tour was developed and tested for a short time on this road. The tour began at the Glacier Guard Station 34 miles east of Bellingham, Washington. Starting at an elevation of 900 feet, the tour took visitors up through several life zones to an elevation of over 4,000 feet at Heather Meadows, 22 miles from the starting point. Because the Mount Baker Highway is a dead end road, visitors returned the way they entered.

Figure 2.--Trail of the Restless Waters, Siuslaw National Forest, Oregon. The trail begins at the lower parking lot, passes through the forest and open areas to the intertidal zone, and then circles back through the forest to the parking lot. A side trail winds down to the Devil's Churn at lower right of picture.

PROCEDURES

Field work for the study was conducted in three phases (table 1). In the "assignment" phase, visitors walking the Trail of the Restless Waters were given one of four cassette tape presentations or used only the existing trail signs. In the "self-selection" phase, also on this trail, a "smorgasbord" of options was offered visitors, including three revised cassette tapes, a trail leaflet, and the option of using the trail and trail signs unassisted. The "auto tour" phase was a limited test of cassettes on the Mount Baker Highway.

Eight different cassette tapes were developed and duplicated to provide 8 to 10 copies of each for the tests. Excess tape was removed from each cassette, leaving only a few seconds at each end without recorded information. For all but the auto tour tape, sides 1 and 2 of each cassette were identical. Thus, after a visitor or group finished one side, the cassette could simply be turned over and issued to the next visitor(s) with no rewinding.

Table 1--*Treatments used in study of cassette tapes for interpretation, Siuslaw and Mount Baker-Snoqualmie National Forests, 1971.*

Assignment phase (Treatments assigned to interested visitors)	Self-selection phase (Visitors selected own treatments)	Auto tour phase (Available to visitors who stopped at Glacier Guard Station)
Treatment 1 (control tape)--A 19-minute cassette tape with no attempt to tie information for the 12 trail stations into a unified theme. Interpretation covered the wind-shaping of trees, effects of shade on ground cover, waxy leaves as an adaptation to salt spray, formation of the Devil's Churn, the origin of waves and tides, local plants and birds, life history of the barnacle, formation of tide pools, the intertidal zone, Indian shell mounds, and characteristics of red alder. Narration nonprofessional. *Treatment 2 (question tape)*--A 22-minute cassette tape identical to Treatment 1 except that key items of information were preceeded by leading questions or were phrased as questions. For example, "Did you know that barnacles are crustaceans, related to the crabs and lobsters?" *Treatment 3 (theme-first tape)*--A 20-minute tape identical to Treatment 1 except introduced by an "overview" showing that all information fit a theme concerning the forces shaping the Oregon coast. *Treatment 4 (theme-last tape)*--A 21-minute tape identical to Treatment 1 except followed by an overview showing that all information fit a theme concerning the forces shaping the Oregon coast. *Treatment 5 (signs only)*--Exposure to the nine existing trail signs without other assistance. These signs interpreted the wind-shaping of trees, formation of the Devil's Churn, the origin of waves and tides, formation and residents of tide pools, beach safety, and where alder trees grow.	*Treatment 6 (12-minute revised tape)*--A 12-minute cassette tape like Treatment 2 but shortened, using fewer questions and professional narration. *Treatment 7 (Devil's Churn tape)*--Like Treatment 6 but using 5 minutes of narration to guide visitors only as far as the Devil's Churn (Trail Station 5). It then offered the option of returning immediately to the parking lot or first walking a few feet to Station 6 and hearing a 3-minute discussion of the forces shaping the Oregon coast. *Treatment 8 (16-minute revised tape)*--Similar to Treatment 6 but giving slightly more detail. *Treatment 9 (Trail leaflet)*--A slightly abridged transcript of Treatment 1, including approximately 2,100 words, presented on a 4-page leaflet made by folding light green $8\frac{1}{2}$- x 11-inch paper to a $5\frac{1}{2}$- x $8\frac{1}{2}$-inch format. This was typed (elite) with space-and-a-half vertical arrangement and reduced to give rather small print having 19 characters per horizontal inch.	*Auto tour tape*--A cassette tape designed for an auto tour of 3 or more hours with several stops and two side trips. Side 1 of the cassette took people the 22 miles from Glacier Guard Station to Heather Meadows, using 25 minutes of narration presented in six segments. The start of each segment was keyed to a mileage marker or other clear feature. Side 1 interpreted the climate, vegetation, and animals of the life zones crossed; glaciation, geology, and rock types; the Nooksack Indians; and early mining history. Side 2 offered two side trips during the return from Heather Meadows: The White Salmon Creek Road (7 minutes of narration in four segments) and the Glacier Creek Road (12 minutes of narration in four segments). These side trips interpreted the mountains, glaciers, and other features visible in two panoramic views; a salmon run; and an early race to the top of Mount Baker and back. Narration was nonprofessional with two male voices alternating. In addition, a recording (poor quality) of an old prospector telling an anecdote was included.

Data Collection

The "assignment" phase was conducted from approximately 9 a.m. to 6 p.m. daily except Tuesday and Wednesday, from June 19 to July 5 and from July 30 to August 9, 1971. Visitors walking the trail (fig. 3) were presented with one of five treatments (four tapes and using the trail signs unassisted), according to a previously developed random schedule. The first 10 visitor groups were presented with the first treatment on the schedule, the next 10 groups with the next treatment, etc. Most groups consisted of family members or friends who arrived at the trail in one vehicle.

Within each group accepting a tape and tape player, one person was required to sign a receipt giving his name, address, and vehicle license number. Tapes and players were issued by a man in Forest Service uniform. Receipts were returned to the individuals when they returned the equipment at the end of the trail.

Each tape interpreted information at 12 numbered stations along the trail. After each segment of the tape, the visitor was told to turn off the tape player until reaching the next numbered post. Narration was in a nonprofessional voice, without music or other special effects. The final message on each tape was:

> Now, please walk on up the trail and turn in the tape player to the man wearing the name tag. Also, because the Forest Service is conducting a study to improve its visitor services, we'd appreciate your answering a few questions concerning this trail. Thank you, and have a good visit to the Siuslaw National Forest and the Oregon coast.

Figure 3.--Visitors listening to taped interpretation of life in the tide pools.

At the end of the trail, each visitor 12 and older was given a clipboard with a pencil and questionnaire attached. (See appendix.) A bench was provided so visitors could sit while answering the questions (fig. 4). Questionnaires were administered by a man in uniform. They covered levels of enjoyment, retention of information, how visitors learned of the trail, and what they liked most and least about it. Questions also covered age, sex, number of people in group, present and expected education, occupation, and place of residence. In addition, each questionnaire provided space and invited comments and suggestions concerning the trail.

Levels of enjoyment were determined by asking each respondent:

> Compared to other trails you have been on or walks you have taken, was the trail
>
> less enjoyable ____
> about as enjoyable ____
> more enjoyable ____

Less enjoyable, about as enjoyable, and more enjoyable were coded as 1, 2, and 3, respectively.

Multiple-choice questions were used to test for short-term retention of information. Because the nine trail signs covered only part of the information provided on the tapes, two questionnaire

Figure 4.--Questionnaires were used to determine how much information visitors to the interpretive trail retained and how much they enjoyed their experiences.

forms were used. There were identical except for color and for the number of test questions. Visitors exposed only to the trail signs were given the short form with four test questions covering information presented on the trail signs. People using the tape players were given the longer form with 14 test questions. Four of these were the test questions used on the short form and covered information given both on the trail signs and on the tapes. The additional 10 test questions covered information presented only on the tapes.

During the first or "assignment" phase of the study, 2,185 questionnaires were administered, of which 2,175 were usable.

The second or "self-selection" phase was conducted on August 9 and from August 12 through 15, 1971, again from approximately 9 a.m. to 6 p.m. For this phase, three revised tapes and a trail leaflet were used. On the revised tapes, both tape length and the number of of questions asked were reduced. Also, the original voice was replaced with that of a professional radio announcer. The 12- and 16-minute revised tapes (Treatments 6 and 8) retained the statement asking visitors to return the tape players and answer a few questions. As in the "assignment" phase, each tape was cut to length with identical recording on the two sides.

During the "self-selection" phase, visitors had a choice of the three revised tapes, the trail leaflet, and walking the trail with no assistance other than the nine existing trail signs. The tapes, players, and leaflets were placed on a table at the entrance to the trail, and each group of visitors approaching the trail was met by a man in uniform who explained the options. Receipts for tapes and tape players were required as in the "assignment" phase.

During this phase, questionnaires were administered only to visitors using the 12- or 16-minute revised tapes (Treatments 6 or 8) or the trail leaflet (Treatment 9). Data for comparing tapes and trail signs had been taken during the "assignment" phase, and the only remaining option (the "Devil's Churn" tape, Treatment 7) covered but a small part of the trail. Records were kept of the number of parties using each tape, using the leaflet, or walking the trail unassisted. Reasons volunteered for not taking the tapes or leaflets were also recorded. Of the 635 questionnaires administered, 632 were usable.

The third or "auto tour" phase began September 4 (Labor Day weekend) and ran continuously through September 12. Because people were not stopped by signs or other means, the only visitors offered the tour tape and tape player were those stopping for information at the Glacier Guard Station. As in the first two phases a receipt was required for each tape player issued.

The tape included 44 minutes of narration in 14 segments. The first side included six segments and took visitors from the Glacier Guard Station to Heather Meadows. The second side offered two short side trips that visitors could take while returning from Heather Meadows. Each side trip included four segments of narration. At the end of each segment, visitors were instructed to turn off the tape player and turn it back on when reaching a specified roadside mileage marker or other readily identified feature. The Mount Baker Highway has these markers at 1-mile intervals.

No questionnaires were used, but each carload of visitors borrowing a tape and player was supplied with a clipboard, pencil, and a 5-1/2- x 8-1/2-inch sheet with the following words at the top:

> The Forest Service is offering these tapes on an experimental basis. If you wish to make comments or suggestions, we will be happy to have them.

Analysis

Data for the Trail of the Restless Waters were examined by analyses of variance and covariance using the NYBMUL program. Orthogonal comparisons were made to test for differences between tapes and the trail signs, between tapes and the trail leaflet, and to examine the effects of using questions within a presentation.

The covariates were used only if they increased the sensitivity of the analyses; they were age, sex, group size, whether or not respondents were residents of Oregon, and education expected at completion. Because many respondents were still in school, expected education was considered a better indicator of attitudes toward learning than was education actually completed.

Because visitors normally travel and use trails with family or friends, questionnaire data were not completely independent. Analyses were therefore made using group (cluster) means rather than individual values for each variable. Also, the NYBMUL program could deal with unequal subclass frequencies at only one level, and this capacity was used to handle the different numbers of visitors exposed to the different interpretive presentations (treatments). Group means, therefore, were not weighted by group size.

Correct responses to the question concerning the effect of shade on ground-cover vegetation ranged from 93 to 97 percent for the various treatments, suggesting that this was common knowledge and provided no information about the effectiveness of treatments. By contrast, for the question having the second highest number of correct responses, percentages for the different treatments ranged from 61 to 93. The shade question was therefore eliminated, leaving 3-item test scores for comparing Treatments 1 through 5 and 13-item test scores for comparing Treatments 1 through 4 and Treatments 6, 8, and 9.

Although statistical analyses were not made for the taped auto tour, visitor reactions and comments were examined for the general insights they provided.

RESULTS

Interpretation of the nature trail by cassette tapes gave significantly greater visitor enjoyment and short-term retention of information than either trail signs or the trail leaflet (figs. 5 and 1). During Phase 1 when tape length averaged over 20 minutes, a few visitors complained of the slowness and said they would prefer leaflets permitting them to scan ahead to the information they desired.

Among the taped presentations, only two important differences were found. First, contrary to expectations, more information was retained from the "control" tape (Treatment 1) than from three tapes testing procedures for increasing what visitors remembered (Treatments 2, 3, and 4). Second, the

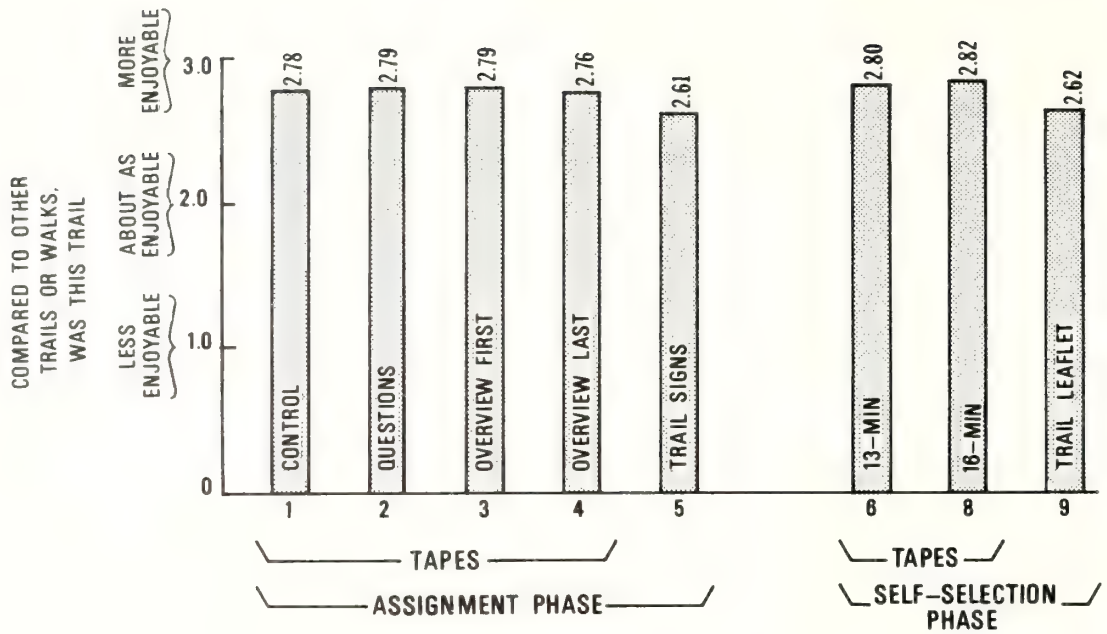

Figure 5.--Although differences in average visitor enjoyment were not great, tapes gave significantly greater enjoyment ($P < 0.01$) than either the trail signs or the trail leaflet. Trail of the Restless Waters, Siuslaw National Forest, Oregon, 1971.

"question" tape (Treatment 2) showed that questions within an interpretive presentation can help visitors remember selected information but only at the risk of decreasing their retention of information that is not emphasized with questions.

Overall test scores for the "question" tape were not significantly different from the scores for the other three tapes tested during the "assignment" phase of the study. However, a significant difference among these treatments was found when questioning within a presentation was analyzed as a dual effect that increased the retention of information emphasized by questions while decreasing retention of information not so emphasized. For a sensitive test of this dual effect, each 13-item test score was divided into two subscores. Subscore A included only the eight test items associated with information emphasized by questioning within the "question" tape (Treatment 2). Subscore B included the remaining five test items. The difference between subscore A and subscore B registers both the increases and decreases in retention caused by questioning. As shown in figure 6, the average difference between subscores A and B was significantly greater for the "question" tape (Treatment 2) than for the other tapes used during the "assignment" phase of the study (Treatments 1, 3, and 4).

Both visitor enjoyment and short-term retention of information increased when experience from the "assignment" phase was used to develop improved tapes for the "self-selection" phase (figs. 5 and 1). This involved shortening, changing to a "professional" voice, using questions sparingly, and eliminating the introductory material that many visitors had disregarded enough that the tape and numbered trail stations became unsynchronized.

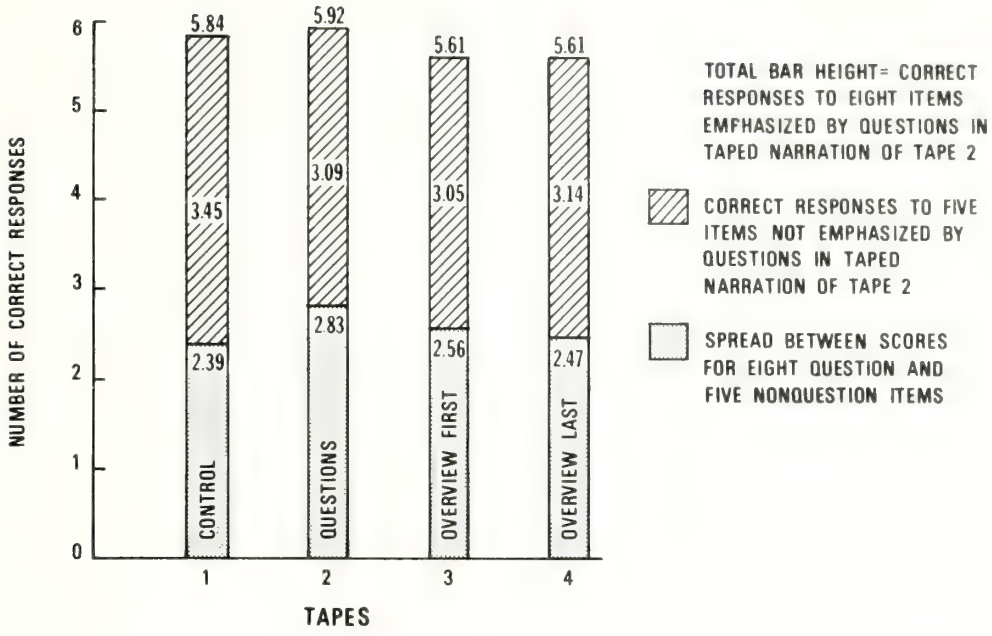

Figure 6.--Questions used within the "question" tape increased retention for information so emphasized (total bar height), while reducing retention for information not so emphasized (hachured portions of bars). The differences between the two subscores (internal scores of bars) reflect the combined (positive and negative) effects of questions within a presentation. This was significantly greater ($P < 0.05$) for the "question" tape than for the tapes without questions. Trail of the Restless Waters, Siuslaw National Forest, Oregon, 1971.

Statistical testing for differences between these two phases was not appropriate because they occurred at different times and may have involved different conditions or different kinds of users.

Of the 548 visitor groups given a choice among five different options during the "self-selection" phase, nearly two-thirds selected one of the three tapes offered (fig. 7). The short "Devil's Churn" tape (Treatment 7, chosen by 30 percent of the visitor groups) was the most popular. This was followed by the trail leaflet (Treatment 9, 22 percent) and the 12-minute revised tape (Treatment 6, 20 percent). Tying for last place (at 14 percent each) were the 16-minute revised tape (Treatment 8) and walking the trail unassisted. The 16-minute revised tape (Treatment 8) provided higher visitor enjoyment and greater retention of information than any other presentation examined in this study.

The taped auto tour was also well received, even though it was a "first cut" with some obvious imperfections. Of the 50 carloads of visitors offered the tape, 41 accepted it, 34 completed side 1 (Glacier to Heather Meadows), and 28 listened to both sides. Thirty-five groups commented on the tape. Of the 108 comments received, 64 were complimentary, 21 registered such complaints as "prospector hard to understand" and 23 were either neutral (such as "hope people return equipment") or suggested such additions as "more geology." The most common category of comments consisted of 35 such nonspecific compliments as "interesting," "well done," "beneficial," and "good variety of information."

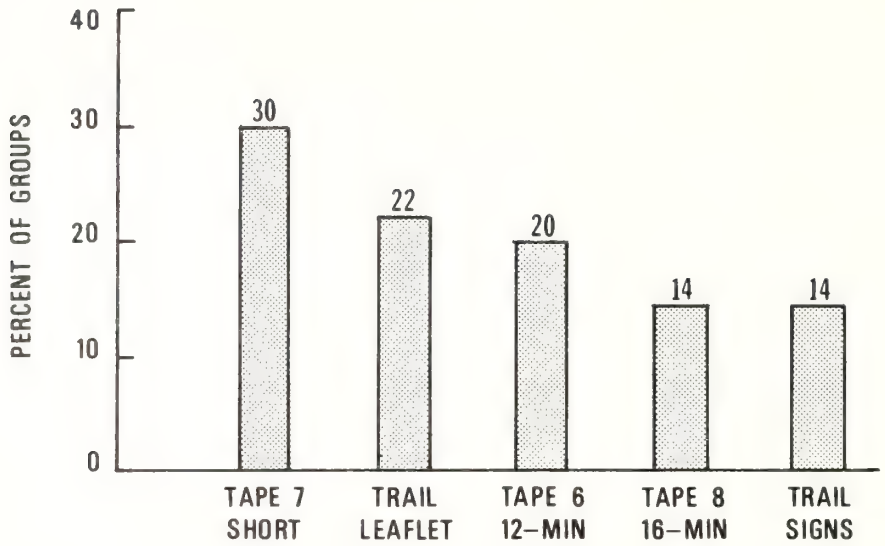

Figure 7.--Percent of visitor groups selecting each of five interpretive options, Trail of the Restless Waters, Siuslaw National Forest, Oregon, 1971.

Twenty of 24 inexpensive tape players (purchased during a "close-out special" at $6 to $8 each) did not withstand continuous use and had to be retired. However, one of them was still going after being issued 134 times and being played for over 39 hours. Three moderately priced brands of tape players ($20 to $30 each) held up quite well, requiring only periodic replacement of batteries. The most heavily used of these was issued 152 times and played for over 42 hours. A "rewind" control was welcomed by the few visitors who wished to hear part of a tape a second time.

No theft or willful damage was encountered during any phase of the study. One inexpensive tape player was damaged beyond repair when drenched by a high wave, along with the visitor who was carrying it among the tide pools. Another visitor hid a tape player in the bushes to avoid such risks while the group he was with spent over an hour among the tide pools. Later he hurried to the parking lot to report the tape player missing and was much relieved to learn that another visitor had spotted it and turned it in. On the Mount Baker Highway, some visitors stayed much later than planned. One tape player was returned late in the evening to a Ranger's residence. Two others were kept overnight and returned the next day.

DISCUSSION

Most of the added visitor enjoyment and retention of information provided by the taped presentations--as compared with trail signs and the trail leaflets--probably resulted because it is easier to listen than to read, especially while trying to examine a variety of attractions. Revision of the trail signs and the leaflet might have increased enjoyment and retention. The signs were not considered the best that could have been done. And the trail leaflet, with

its small print and lack of illustrations, was also far from outstanding. Substantial improvements, however, would have been required to equal the effectiveness achieved by tapes. And as the author's first such venture, the tapes also left room for improvement.

In contrast with the results reported here, Feldman (1975) found retention of information from a well-illustrated auto tour brochure to be approximately the same as from cassette tapes and players. Perhaps reading in a car is easier than on a trail. Also, brochures usually would have been read aloud by one passenger, fixing details in his mind while providing the driver and other passengers with a spoken presentation.

Two factors help to explain the greater retention found for the "control" tape than for the other tapes used in the "assignment" phase. The novelty of the cassette tapes and players seemed to motivate high visitor interest for all tapes used. Thus, selected approaches for making the "treatment" tapes extra effective apparently did not add substantially to the high interest and motivation that already prevailed. Furthermore, the treatment tapes had some weaknesses, especially the tape introduced by an "overview." This had the lowest retention scores of any tape tested.

The introduction on this tape took 1 minute and 50 seconds and was designed to "preprogram" people and provide a conceptual framework to tie details together--effects Screven found for a pretest in a museum setting.[1/]

However, this lengthy introduction did not accommodate the desire of most visitors to walk down the trail immediately after receiving a tape player. Even when asked to stand and listen before walking, most visitors turned on the player and began moving, usually walking as far as Station 3 before hearing interpretation for Station 1, 10 feet from where tape players were issued.

Surprisingly, the poor coordination between numbered stations and trail segments at the beginning of the trail resulted in reduced retention primarily among the last 5 of the 12 stations. By the time visitors reached these stations, they had ample opportunity to synchroniz the numbered posts and tape sequences. The initial lack of synchronization may have affected people's expectations so that getting tapes and trail stations synchronized did not seem especially important. For example, some groups let the tape play continuously but also walked continuously so the tape never did catch up with their position.

If visitors tried to match the unsynchronized tapes and trail stations in their minds, they would have had to deal with a continually growing amount of taped information and visual impressions. A growing burden upon memory is consistent with reduced retention toward the end of the trail. However, levels of enjoyment did not differ significantly among the four tapes tested during the "assignment" phase of the study. The fact that an apparent burden upon memory did not antagonize people enough to reduce their enjoyment suggests that many visitors in recreational settings feel little anxiety or compulsion about how much they are learning.

As an alternative explanation, upon reaching each early trail station, visitor

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[1/] Personal communication with C. G. Screven, Professor of Psychology, University of Wisconsin at Milwaukee, 1970.

In contrast with Screven's pretest, the introductory overview did not suggest to visitors that they were involved in an experiment and might be tested on what they remembered.

might have reviewed what they had already heard about it on tape. If, toward the end of the trail, visitors got the tape and trail stations synchronized, they would no longer need to review information at each station encountered. Such differences in the amount of review are also consistent with reduced retention toward the end of the trail.

The effects of questions incorporated into the "question" tape (Treatment 2) suggest that people's short-term memory is limited. While questions called attention to specific information and increased its retention, they simultaneously seemed to downgrade the importance of other information and increased its probability of being lost before getting incorporated into longer-term memory.

A few visitors complained that the frequent questions on the "question" tape made it too much like a "schoolteacher." The increased effectiveness achieved for the 12- and 16-minute revised tapes, however, suggests that the sparing use of questions to call attention to key points can add to the overall effectiveness of a presentation without antagonizing visitors.

Although use of a "professional" voice on these revised tapes coincided with increased visitor enjoyment and retention of information for the nature trail, professionalism is not necessarily the relevant factor. During revision of the trail tapes, one radio announcer was tried and rejected as conveying little understanding, concern, and enthusiasm for the subject matter. A useful distinction might be made between general narration and special effects. For general narration, a voice with pleasing quality seems desirable, provided it does not sound too "canned" or "slick." However, for special effects, other qualities might be preferred. Thus many visitors enjoyed the gravelly-voiced prospector and his colorful speech and anecdote, even though poor recording quality made him difficult to understand.

The pattern in which visitors chose among the five different presentations offered during the "self-selection" phase indicates that not all visitors want the same kind of presentation. The great popularity of the "Devil's Churn" tape (Treatment 7) was undoubtedly affected by the preponderance of visitors who stopped in response to the highway sign reading "Devil's Churn Overlook, 1,000 feet" and who therefore intended only a brief stop. If other strategies had been used to direct people to the trail, the order of visitors' preferences among the five presentations might have been different. A "quick" presentation such as the "Devil's Churn" tape is likely to be welcomed by the more hurried visitors of many settings. However, a majority of the people taking this tape listened to the 3 minutes of optional information as well as the main 5-minute presentation.

Because the "assignment" and "self-selection" phases could have involved slightly different conditions or kinds of visitors, neither enjoyment nor retention levels can be directly compared between the two phases. More importantly, the options available during the "self-selection" phase were selected by visitors rather than being assigned according to a study plan. Thus the greater enjoyment and retention found for the 12- and 16-minute revised tapes (Treatments 6 and 8) may be partly explained by the likelihood that, given the opportunity, the more highly motivated visitors will select the longer tapes. This may partly explain why

the 16-minute revised tape had the highest enjoyment and retention level of any presentation tested. During the "self-selection" phase, less motivated visitors had several less demanding options. The improved showing of the 12- and 16-minute revised tapes suggests as well that initial experience and evaluation permit the final version of nearly any presentation to be improved.

The trail signs and trail leaflets also were tested during different phases, with only the leaflets being "self-selected." Thus these two treatments can be compared only in a very general way. Some visitors wanted information they could read while on the road or at home, and the leaflet did serve this need and as a souvenir.

The levels of enjoyment shown in figure 5 probably reflect the tendency of most people to be agreeable rather than critical when asked for an opinion about someone's efforts. This "congeniality bias" probably caused ratings for all treatments to be compressed toward the high end of the scale. It is likely that visitors exposed to the different treatments actually experienced greater differences in enjoyment than their answers indicated.

Costs for using cassette tapes and tape players appear to be quite reasonable. If a $30 tape player gave, on the average, 300 trouble-free performances before being fully depreciated, the tape player cost per visitor group would be 10 cents. Costs for tapes, batteries, developing and recording taped presentations, personnel (administering the tapes and players in conjuction with other duties), etc. would depend greatly on the scale of the operation but would probably add between 5 and 20 cents per visitor group. Dividing by the average group size at the Trail of the Restless Waters, slightly over 3.5, would give an average cost per visitor contact of between 4 and 9 cents. In view of the high effectiveness of the tape players, costs of this order would seem extremely reasonable.

The highly favorable response to the auto tour probably resulted in part because it was offered only to visitors who stopped for information and were thus self selected on the basis of a prior interest in information. However, most interpretation involves noncaptive audiences that are to some extent self selected.

Two points emerged from experience with the auto tour. First, existing mileage markers at 1-mile intervals were a key factor in successful sychronization of the tapes with points of interest. These had been erected by the Washington Highway Department and required only brushing out for improved visibility. Second, visitors will volunteer a great amount of feedback if offered the opportunity. Although compilation of volunteered responses provides no unbiased estimates of visitor enjoyment or recall, it quickly identifies any facets of a presentation that are working especially well or poorly. In other words, volunteered responses provide the kind of information an interpreter can use to identify major problems with a presentation before they become permanent.

The total absence of theft or willful damage was encouraging. Identical results have been obtained in New York and Colorado.[2/] [3/] Signing a receipt

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[2/] Personal communication with Robert L. Feldman, 1974. Feldman is currently Assistant Professor, Natural Resources Management Department, California Polytechnic State University, San Luis Obispo.

[3/] Personal communication with Merrit Esmiol, Visitor Information Specialist, U.S. Forest Service, Rocky Mountain Region, Lakewood, Colorado, 1975.

giving one'e vehicle license number seemed a sufficient guarantee of returned equipment among the kinds of visitors who seek detailed interpretation. However, unless such receipts are backed by a real willingness and ability to recover unreturned equipment, they might become widely recognized as an empty threat; and equipment losses might become a problem. Provisions would then need to be made for holding a cash deposit while visitors had equipment. During the study many visitors were astonished that a deposit and use charge were not required--indicating that they were already prepared to make a deposit.

GUIDELINES AND CONCLUSIONS

Although it is not possible to prescribe for all conceivable circumstances from the results of one study, the following guidelines and conclusions seem warranted until additional experience and research results are available:

1. Cassette tapes in portable players can provide substantially greater enjoyment and understanding on an interpretive trail than can be expected, on the average, from either trail signs or trail leaflets.

2. To avoid added costs for administering tapes and tape players, they should be offered at a visitor center or other interpretive facility where personnel are already available and can handle them in conjunction with other duties.

3. Although requiring a signed receipt giving address and vehicle license seemed an adequate safeguard against theft or willful damage during the study, the "honor system" may not work over extended periods. Organizations loaning tapes and players probably should develop procedures for recovering equipment not returned, for holding a deposit sufficient to guarantee such return, or both.

4. For using cassette tapes and tape players on an interpretive trail, an on-the-ground cost per visitor contact of between 4 and 9 cents is likely, depending on the scale of the operation.

5. For a given interpretive trail, tour, or attraction, different tapes should be developed to fit different sets of visitor needs and desires. Factors to consider include hurried versus deliberate visitors, different age groups, different language groups, people wanting advanced versus those wanting elementary presentations, and repeat visitors who would enjoy exposure to new sets of subject matter.

6. Tapes lend themselves to easy revision and should be tried out on visitors before being put in final form.

7. In developing taped auto tours, each tape segment should be keyed to a mileage marker or other readily identified feature.

8. Questions within a taped presentation can increase effectiveness if they are used sparingly to emphasize key points.

9. If introductory or orientation information is to be given at the beginning of a tape, visitors must have sufficient walking (or driving) distance that they can proceed at normal speed without physically passing the first interpretive station before encountering it on tape.

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APPENDIX

O.M.B. No. 40 - 71045
Expires 12/31/71

QUESTIONNAIRE FOR RESTLESS WATERS NATURE TRAIL, SIUSLAW NATIONAL FOREST

Compared to other trails you have been on or walks you have taken, was this trail

less enjoyable _____
about as enjoyable _____
more enjoyable _____

How did you find out about this trail?

from signs _____
tourist guide _____
from previous trip _____
from friends or relatives _____
from Forest Service _____
other (please specify) _____

What do you consider the most enjoyable thing about this trail?

What do you consider the least enjoyable thing about this trail?

The wind shapes the trees here mostly by

bending the wood _____
killing some of the buds _____
breaking off some of the branches _____

Cape Perpetua was named by

Captain George Vancouver _____
Captain Louis Perpetua _____
Captain James Cook _____

The wax on the needles of Sitka spruce and on the leaves of salal helps them to

resist the drying effects of the wind _____
resist attacks by insects _____
resist intense sunlight _____

The Devil's Churn started as

a lava tube _____
a stream channel _____
a crack in the rock _____

The Devil's Churn is in a layer of rock that is

93 thousand years old _____
37 million years old _____
58 million years old _____

Here on the Oregon Coast the amount of vegetation growing on the forest floor depends mostly on

the amount of light reaching it _____
how much of it is eaten by animals _____
the steepness of the ground _____

For this part of the Oregon Coast, the usual cause of extra large waves is

a sudden shift in the earth's crust, deep on the ocean floor _____
an unusually strong gust of wind, far out at sea _____
waves from 3 different directions arriving at the same time _____

A 1-year-old sea gull will usually be

white _____
white with gray wings _____
brownish and dull colored _____

Clouds and rain are common on the Oregon Coast because

the dense forests make the air moist and cause rain _____
moist air from the ocean is cooled as it rises over the mountains _____
salt in the air makes the water vapor condense _____

The highest tides occur when

the sun, moon, and earth are all in line _____
the moon is in its first or third quarter _____
the sun, moon, and earth are not in line _____

In the zones caused by the rising and falling tides, animals are most likely to be permanently attached

in the zone covered by water only a few hours a day _____
in the middle zone covered by water about half the time _____
in the zone covered by water most of the time _____

Barnacles are

mollusks, related to oysters and clams _____

crustaceans, related to the crabs and lobsters _____

polyps, related to the corals _____

Barnacles are

free to swim in the ocean only after changing to adult form _____

free to swim in the ocean only during the early part of their lives _____

attached to rocks or other surfaces throughout their lives _____

Red alder trees almost always start their lives

in a dense forest _____

where soil has been uncovered by a disturbance _____

where soils are shallow and rocky _____

To do a better job of designing nature trails we need to know whether different groups of people enjoy and remember different kinds of things from them. For this we need the following information:

Male_____ Female_____

Your age_____

Number of people in your group as you walked on this trail_____

The highest year of school you have completed (please circle):

Grammar School								High School				College				Post Graduate		
1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7+

If you are still in school or intend to go back, please circle the highest year you expect to complete.

Grammar School								High School				College				Post Graduate		
1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7+

What is your occupation?_____

Where do you live?_____
City State, Province, or Country

If you wish, please use the back of this page to add any other comments or suggestions about this trail.

Wagar, J. Alan.
1976. Cassette tapes for interpretation. USDA For. Serv. Res. Pap. PNW-207, 20 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Interpretation using portable tape players and cassettes provided significantly greater enjoyment and short-term retention of information on a visitor trail than either trail signs or a trail leaflet. Tape format using questions increased retention of the information so emphasized but at the risk of reducing retention of other information. On-the-ground costs were estimated as between 4 and 9 cents per visitor contact.

KEYWORDS: Recreation, information and education, information media, interpretation, environmental education.

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The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

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Juneau, Alaska
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La Grande, Oregon
Portland, Oregon
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Mailing address: Pacific Northwest Forest and Range Experiment Station
P.O. Box 3141
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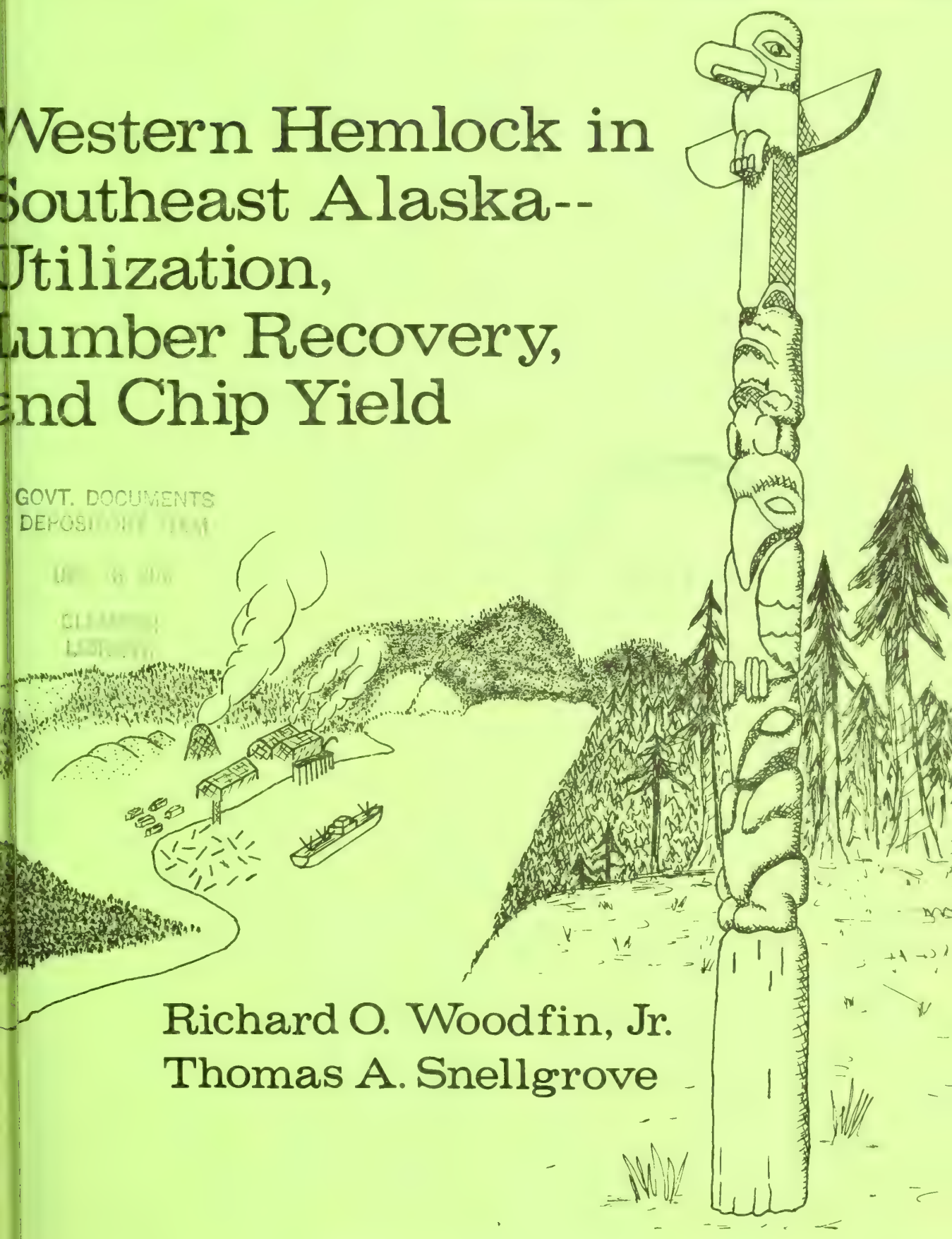
1976
USDA FOREST SERVICE RESEARCH PAPER PNW-208

Western Hemlock in Southeast Alaska--Utilization, Lumber Recovery, and Chip Yield

GOVT. DOCUMENTS
DEPOSITORY ITEM



Richard O. Woodfin, Jr.
Thomas A. Snellgrove

NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE

PORTLAND, OREGON
U.S. DEPARTMENT OF AGRICULTURE

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METRIC CONVERSION TABLE

1 inch	=	2.540 centimeters
1 foot	=	0.305 meter
1 cubic foot	=	0.028 cubic meter
1 pound	=	0.453 kilogram

WESTERN HEMLOCK IN SOUTHEAST ALASKA--UTILIZATION, LUMBER RECOVERY, AND CHIP YIELD

Reference Abstract

Woodfin, Richard O., Jr., and Thomas A. Snellgrove.
1976. Western hemlock in southeast Alaska--utilization, lumber recovery, and chip yield. USDA For. Serv. Res. Pap. PNW-208, 33 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Lumber recovery from western hemlock from southeast Alaska National Forest land is presented with cubic volume yields, cull log lumber recovery, estimates of chippable wood, and logging residue from sample trees.

KEYWORDS: Western hemlock, *Tsuga heterophylla*, wood utilization, lumber yield studies, sawmill recovery studies, log grading, cubic volume measure, chip production, southeast Alaska.

RESEARCH SUMMARY

Research Paper PNW-208

1976

This report presents lumber recovery information on a sample of western hemlock trees selected from southeast Alaska National Forest land and sawn at a southeast Alaska mill cutting for the Japan export market.

A total of 1,261 sawn-length logs produced about 335,400 board feet of lumber. Over 88 percent of this volume was in 4-inch-thick items, primarily nominal 4 by 4's.

Sawing the 1,165 noncull logs resulted in a 20-percent overrun from net scale. The cubic lumber recovery was 48 percent of the gross cubic log volume. In contrast, the 96 cull logs yielded only a 26-percent cubic recovery.

Lumber grade recovery was concentrated in two grades, Standard and Construction.

Average scaled defect for the 1,165 sawn, noncull logs was 19.6 percent. Defect percentages were lowest for the Peeler and No. 3 grade logs.

The calculated pounds of ovendry chippable wood varied substantially over the diameter range.

Logging residue accounted for 23.3 percent of the total tree volume. Residue types recognized were broken logs, long butts, unused volume to an 8-inch top (includes cull logs left in the woods), and the volume between the used top and total height. These amounted to 3.2 percent, 5.7 percent, 3.6 percent, and 10.8 percent, respectively, of total tree volume.

Introduction

Southeast Alaska contains an estimated 107 billion board feet of old-growth western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) sawtimber (USDA Forest Service 1973) which represents about 43 percent of the western hemlock sawtimber in the Western United States. About 39 percent of this sawtimber volume is in the 21- to 30-inch diameter range; another 30 percent is in larger trees (Hutchison 1967). Less than 5 percent is comprised of the higher quality Peeler and No. 1 grade logs.[1]

Alaska's forest products industry is principally export oriented with the major volume of lumber manufactured as cants designated for Japan. The pulpmills and sawmills are primary manufacturing plants whose output is further processed by secondary plants to obtain finished products.

Western hemlock provided only about 14 percent of the total volume of cants and lumber exported from southeast Alaska in 1967; by 1973 this had increased to 52 percent. Western hemlock from Alaska now comprises about 15.8 percent of the total amount of softwood lumber exported from the west coast and about 55 percent of all the western hemlock exported from the west coast. Such increases point up the need for periodically updating lumber recovery information.

Objectives

This paper presents the results of a 1970 study to determine lumber recovery volumes and grade yields from a representative sample of western hemlock sawtimber in southeast Alaska. This lumber yield information, produced under current industrial manufacturing practices, can provide the Alaska forest products industry and public agencies with an improved basis for determining timber value and estimating product yields.

Timber quality log surface characteristics were identified, measured, and recorded for all the trees processed. The relationship of these characteristics to lumber yield is being used to develop improved log grading and tree valuation systems for western hemlock.

Procedures

Timber Sample

Approximately 360 trees were selected from 12 sample areas on the North and South Tongass National Forests. Figure 1 shows the approximate location of the areas. From each of these areas, approximately 30 trees were selected to represent the size and quality of timber available to a southeast Alaska sawmill rather than the normal log mix of a mill. This permits any southeast Alaska mill to apply the study results to its particular log grade and diameter mix. Sample stratification was by tree size and a quality determination that was the grade (USDA Forest Service 1959) of the first 16-foot log in each tree.

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[1]Grade as defined by USDA Forest Service (1959).

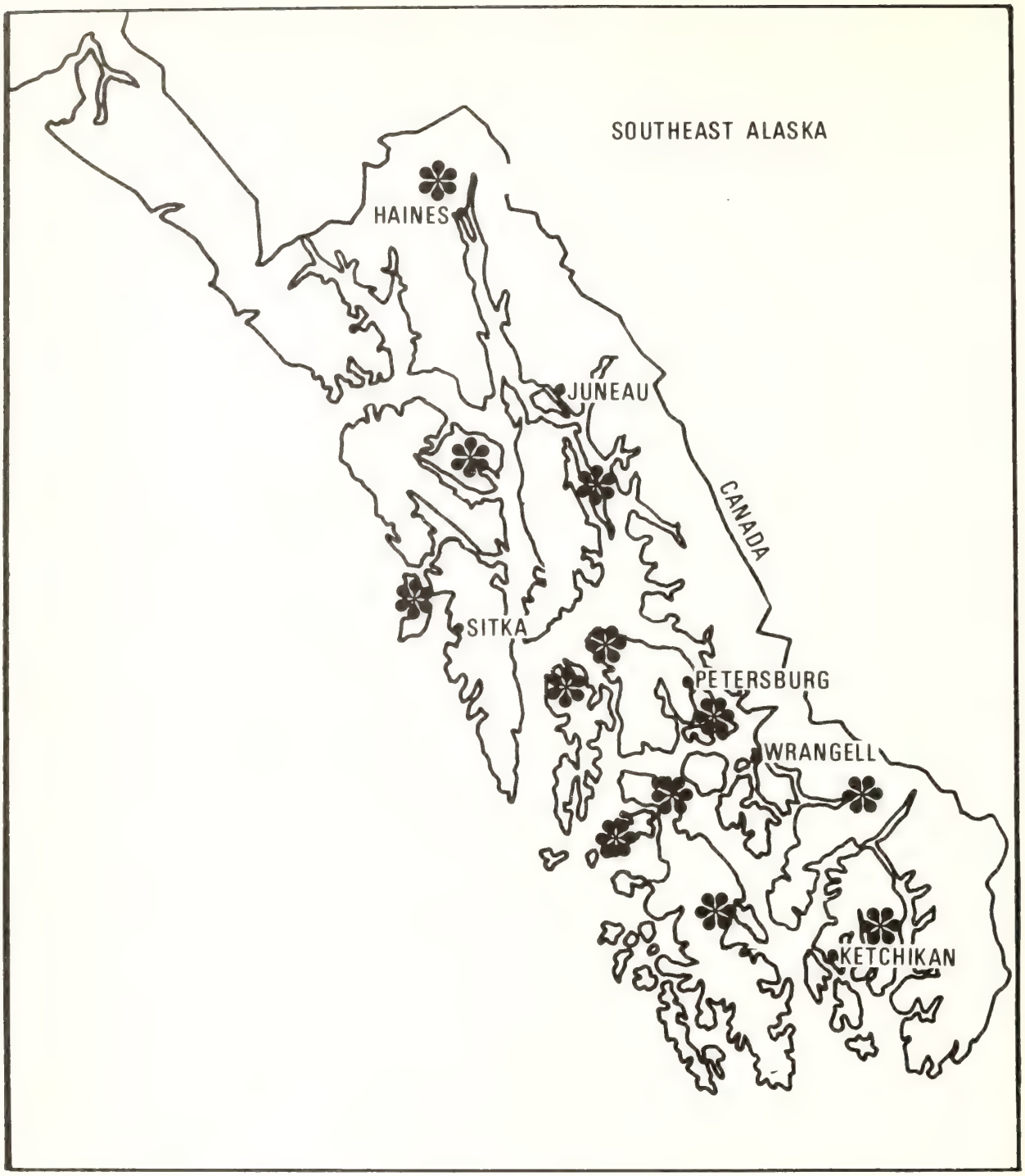

Figure 1.--Approximate location of the 12 sample areas.

Logging, Identification, and Diagraming

The study trees were felled and bucked into saw logs by cooperating logging contractors according to normal industry practice in southeast Alaska. Each log was tagged in the woods to identify its origin with respect to tree and position in the tree. All logs were skidded by tractor or rubber-tired equipment.

The surface characteristics of each log were identified and measured after the trees were felled and before skidding. The relationship of these external characteristics of a log to its eventual lumber grades and yield becomes the basis for analysis to refine or develop log or tree grades.

Transportation and Scaling

The study logs from each area were rafted to the Alaska Wood Products, Inc., sawmill at Wrangell. Here a U.S. Forest Service representative applied the Puget Sound Log Scaling and Grading Bureau (1969) rules to all study logs.

The sample trees produced 1,261 sawn-length[2] logs. Tables 1 and 2 present the log distribution by length and grade for rafted or woods-length[3] logs and for bucked or sawn-length logs.

The sawn-length logs included 0.2 percent Peeler grade logs, 4.3 percent No. 1 grade, 45.0 percent No. 2 grade, 42.9 percent No. 3 grade; the additional 7.6 percent of the logs were culled for defect.

Sawing

The study logs were sawn under nearly normal processing procedures and production rates at the Alaska Wood Products, Inc. mill. Production equipment included a band headsaw, cant gangsaw, horizontal band resaw, and an edger. The sawmill cooperated by cutting the logs to recover optimum value of the logs consistent with their normal manufacturing procedures to produce rough green 4- by 4-inch items ("baby squares") for export.

Lumber Grading

All sawn items were graded under the supervision of a Pacific Lumber Inspection Bureau grader. He applied the West Coast Lumber Inspection Bureau Standard Grading and Dressing Rules (West Coast Lumber Inspection Bureau 1956) and placed each item into one of the following lumber grades:

B and Better Select	Construction
C Select	Standard
D Select	Utility
Select Structural	Economy

[2]Sawn-length logs are logs in lengths as rebucked in the mill.
[3]Woods-length logs are logs in lengths as bucked in the woods.

Table 1.--*Distribution of scaled-length, western hemlock logs by length and log grade for southeast Alaska*

Log length (feet)	Log grade[1/]				Cull	Total
	Peeler	No. 1	No. 2	No. 3		
	Number of logs					
10	0	0	0	3	0	3
12	0	0	0	10	0	10
14	0	0	0	3	1	4
16	0	2	2	10	2	16
18	0	0	1	4	1	6
20	0	1	3	13	2	19
22	0	0	5	17	1	23
24	0	0	3	21	5	29
26	0	7	14	32	3	56
28	0	0	1	5	1	7
30	0	1	2	11	0	14
32	0	0	19	26	3	48
34	0	1	5	11	1	18
36	0	2	13	18	4	37
38	0	0	2	9	0	11
40	3	17	99	93	11	223
42	0	0	1	6	0	7
44	0	0	4	10	0	14
46	0	0	14	12	0	26
48	0	0	3	6	1	10
50	0	0	2	5	1	8
52	0	0	42	44	4	90
54	0	0	0	2	0	2
56	0	0	0	1	0	1
58	0	0	0	0	1	1
60	0	0	0	2	0	2
62	0	0	0	0	0	0
64	0	0	0	2	0	2
66	0	0	0	5	0	5
68	0	0	0	3	0	3
70	0	0	0	3	0	3
72	0	0	0	1	0	1
74	0	0	0	2	0	2
76	0	0	0	3	0	3
78	0	0	0	1	0	1
80	0	0	0	2	0	2
Total	3	31	235	396	42	707

[1/] General Log Grading Rules for Sitka Spruce and Western Hemlock. USDA Forest Service, 2441.4, Alaska Region, 1959.

Table 2.--*Distribution of sawn western hemlock logs by length and log grade for southeast Alaska*

Log length (feet)	Log grade[1/]				Cull	Total
	Peeler	No. 1	No. 2	No. 3		
	Number of logs					
10	0	0	0	5	0	5
12	0	0	32	29	12	73
14	0	0	120	58	21	199
16	0	1	21	27	5	54
18	0	0	26	39	2	67
20	1	29	164	143	32	369
22	0	1	15	29	6	51
24	0	0	25	42	4	71
26	2	23	164	162	14	365
28	0	0	0	7	0	7
Total	3	54	567	541	96	1,261

[1/] General Log Grading Rules for Sitka Spruce and Western Hemlock. USDA Forest Service, 2441.4, Alaska Region, 1959.

Cubic Volume: Logs, Sawdust, and Coarse Chippable Residue

The gross cubic log volume (G.V.) was computed by the following formula:

$$G.V. = \pi L \frac{(D_1^2 + D_1 D_2 + D_2^2)}{12 \times 144};$$

where π = constant pi, 3.1416,

L = log scaling length in feet,

D_1 = log scaling diameter in inches, small end,

D_2 = log diameter in inches, large end.

Sawdust volumes were calculated using one-half the average saw kerf width and the computed surface area of the lumber from each log.

Coarse or chippable residue volume is the difference between gross cubic log volume and lumber volume plus sawdust volume. This indirect method of calculation includes the small amount of sawdust from the saw kerf of the slabs and edgings.

Results and Discussion

Table 3 summarizes the log scale, lumber tally, and cubic volume of the logs in the study for each log grade and for all grades combined. A more detailed breakdown of these results, including lumber grade yields by diameter and log grade, is presented in appendixes 1 and 2.

Appendix 1 presents the recovery volume and lumber grade yields by log grade and diameter classes for sawn-length logs; appendix 2 contains the same information for woods-length logs. For example, the average cubic recovery for No. 2 grade logs was 49 percent (see table 9) and for cull logs 26 percent (see table 11).

We included data for both sawn- and woods-length logs when we thought it might be of use and interest, but generally only the data for sawn-length logs are discussed.

Defect

Defect percentages by individual log grade and all grades combined are shown in table 3. The average defect percent for noncull, sawn-length logs was about 20 percent compared with about 22 percent for noncull, woods-length logs. The primary reason for the sawn-length logs having less scaled defect than the woods-length logs is that if the woods-length log is bucked at the mill, the defect in that log may be confined to one of the sawn-length logs. This may result in one of the sawn-length logs being culled.

Overrun, Lumber Recovery Factor, and Cubic Recovery

The average overrun for all noncull, sawn- and woods-length logs was 20 percent and 35 percent (120 and 135 recovery percent), respectively. The differences in overrun between log grades for both sawn- and woods-length logs are due to the diameter distributions between grades, to the various types and amounts of defects between grades, and to the relationship of both of these factors. Overrun as used here is board-foot lumber tally volume less net Scribner log scale divided by net scale times 100.

The 665 noncull, woods-length logs produced 315,481 board feet of lumber; when bucked, the noncull, sawn-length logs produced 309,187 board feet of lumber (table 3). As described above, this difference in lumber tally volume is due to some logs being considered cull when bucked into the sawn length. The total gross and net scales for all woods-length, noncull logs were 299,170 and 232,840 board feet, respectively.

Table 3.--*Log scale, lumber tally, and cubic volume of sawn-and woods-length western hemlock logs by log grades used in southeast Alaska*

Log grade	Number of logs	Log scale[1]		Defect	Lumber tally			Cubic volume				
		Gross	Net		Volume	Recovery percent[2]	Lumber recovery factor	Log	Lumber	Lumber recovery percent[3]	Sawdust	Residue
		- -Board feet - -		Percent	Board feet		Bd.ft./cu.ft.	- - -Cubic feet- - -			- - Cubic feet - -	
Sawn-length logs:[4]												
Peeler	3	2,620	2,310	11.8	2,878	125	8.04	358.15	240.23	67	32.40	85.52
No. 1	54	48,370	35,260	27.1	44,430	126	5.86	7,583.69	3,729.12	49	489.73	3,364.84
No. 2	567	206,270	163,990	20.5	192,017	117	5.83	32,957.21	16,080.96	49	2,143.95	14,732.30
No. 3	541	62,210	55,210	11.3	69,862	127	5.51	12,666.50	5,842.91	46	787.93	6,035.66
Total or weighted average	1,165	319,470	256,770	19.6	309,187	120	5.77	53,565.55	25,893.22	48	3,454.01	24,218.32
Woods-length logs:[4]												
Peeler	3	4,350	3,620	16.8	4,675	129	5.66	826.05	390.69	47	52.70	382.66
No. 1	31	42,820	28,140	34.3	37,070	132	4.40	8,427.57	3,110.26	37	409.92	4,907.39
No. 2	235	169,980	132,380	22.1	172,367	130	5.17	33,351.32	14,442.43	43	1,921.07	16,987.82
No. 3	396	82,020	68,700	16.2	101,369	148	5.32	19,067.04	8,480.76	44	1,139.29	9,446.99
Total or weighted average	665	299,170	232,840	22.2	315,481	135	5.11	61,671.98	26,424.14	43	3,522.98	31,724.86

[1] Sawn-length logs: as scaled by Forest Service scaler, applying Puget Sound Log Scaling and Grading Bureau rules, Scribner Decimal C log rule. Woods-length logs: as scaled by Forest Service scaler, applying Puget Sound Log Scaling and Grading Bureau rules, Scribner Decimal C log rule.

[2] Lumber tally volume as a percent of net scale volume.

[3] Lumber cubic volume as a percent of log cubic volume.

[4] Cull logs not included.

The mix of log sizes and quality in this study resulted in a rough green lumber cubic volume recovery of approximately 43 percent from woods-length logs and 48 percent from sawn-length, noncull logs (table 3). This compares with 56-percent cubic-foot recovery from a sawn sample of woods-length Sitka spruce logs in southeast Alaska (Lane et al. 1972). By comparison, a series of old-growth Douglas-fir studies (Lane et al. 1973) in the Pacific Northwest had a 63-percent cubic-foot recovery from woods-length logs.

The LRF for this Alaska western hemlock study was 5.1 board feet per cubic foot of log volume for woods-length logs and 5.8 board feet per cubic foot for sawn-length logs (see table 3). These figures are based on nominal lumber or cant tally and gross cubic log volumes.

Lumber Grade Yields

Table 4 and figures 2 and 3 present the distribution of average lumber grade yields by log grades. There is a very noticeable decrease in the percentage of C and Better lumber from the Peeler log grade (45.8 percent) to the No. 3 log grade (1.1 percent). This is balanced by the increase in the percentage of Construction and Standard lumber for the same log grades: 37.0 percent to 58.5 percent.

Note in figure 2 the consistent production of Select Structural and Utility grades of lumber for all log grades. These two grades account for about 15 percent of the total study lumber tally but do not differ substantially between log grades.

Items 4 inches thick accounted for 88.2 percent of the lumber volume produced, whereas items 2 inches thick accounted for about 11.8 percent and 1-inch thick items for less than 0.1 percent. Lumber items measuring a nominal 4 by 4 inches accounted for 87.0 percent of the study volume.

Table 4.--*Average lumber grade yields expressed as a percent of lumber tally volume by log grade for southeast Alaska western hemlock*

Log grade	Number of logs	Lumber tally volume	Lumber grades					
			C and Better Select	Select Structural	Construction	Standard	Utility	Economy
		Board feet	- - - - - - - - - - *Percent of lumber tally volume* - - - - - - - - - -					
Sawn-length logs:								
Peeler	3	2,878	45.76	4.14	20.60	16.47	8.55	4.48
No. 1	54	44,430	39.16	5.10	17.07	15.50	16.14	7.03
No. 2	567	192,017	15.02	10.84	25.38	22.13	20.54	6.09
No. 3	541	69,862	1.11	9.11	29.81	28.63	24.74	6.60
Total or average	1,165	309,187	15.60	9.60	25.20	22.60	20.70	6.30
Cull	96	26,234	22.67	2.10	12.41	18.75	33.72	10.35
Woods-length logs:								
Peeler	3	4,675	48.64	9.39	10.93	11.36	14.16	5.52
No. 1	31	37,070	41.63	5.80	18.11	14.01	14.00	6.45
No. 2	235	172,367	17.49	10.37	24.15	21.56	20.02	6.41
No. 3	396	101,369	2.58	9.20	29.02	26.96	25.75	6.49
Total or average	665	315,481	16.00	9.40	24.80	22.30	21.10	6.40
Cull	42	19,940	19.13	1.60	13.62	22.89	32.68	10.08

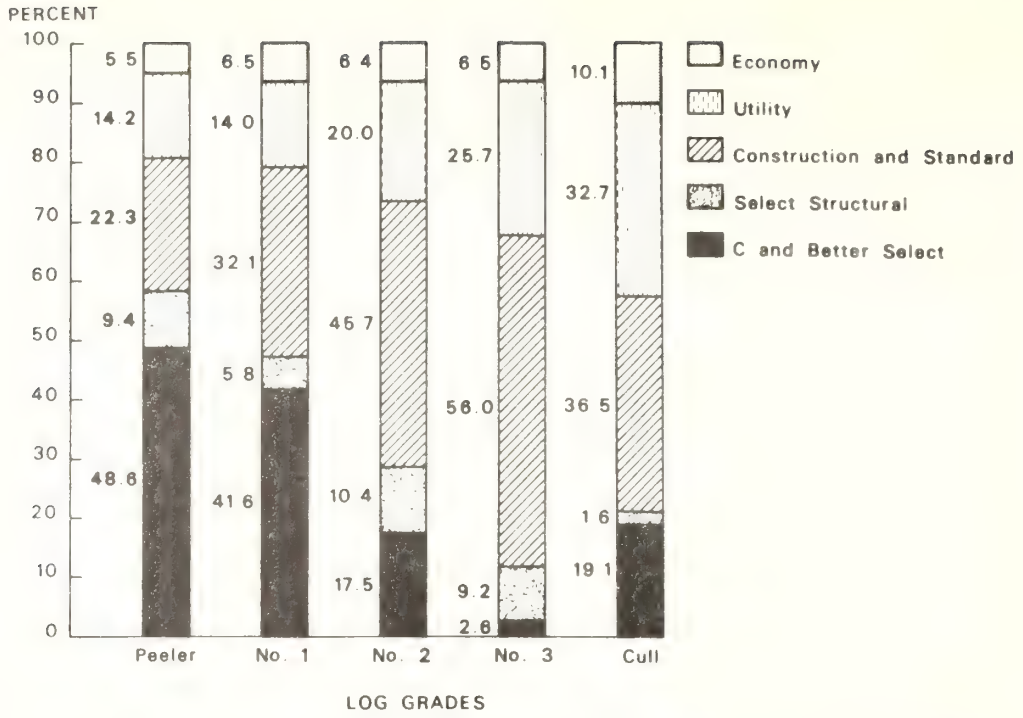

Figure 2.--Average yield from woods-length logs by lumber grade.

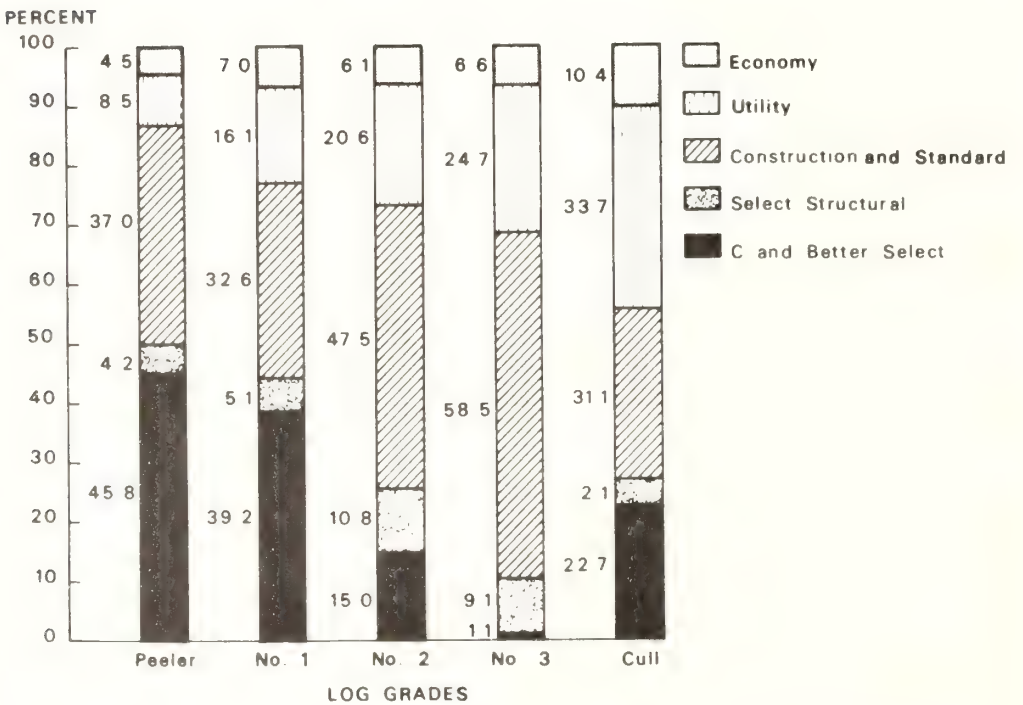

Figure 3.--Average yield from sawn-length logs by lumber grade.

From the sawn-length logs (fig. 3), Standard and Construction lumber grades accounted for at least 30 percent of the lumber grade recovery from any log grade, including culls. Further evidence of the yield of high value wood from cull logs is shown by the nearly 23-percent recovery in C and Better Select cants. For example, consider the cull 24-inch log in figure 4. The net scale of this log was 140 board feet. Actual lumber tally was 220 board feet. About 50 percent of this log's lumber recovery was Construction grade. The gross log volume was 71.9 cubic feet with 18.1 cubic feet (25.2 percent) recovered as lumber.

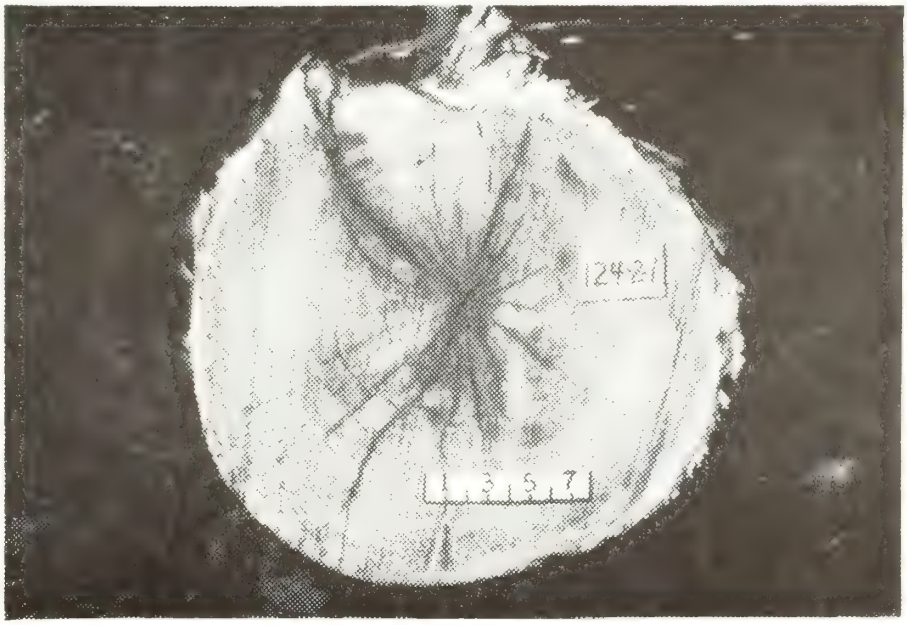

Figure 4.--A 24-inch cull western hemlock log with a gross scale of 450 board feet, net scale of 140 board feet, a lumber yield of 220 board feet, and 25.2-percent recovery of gross cubic-foot log volume.

Chip Recovery

The forest products industry is moving toward use of cubic volumes to express mill input and product output yields. Several grading and scaling bureaus now provide a cubic scale of logs if requested. Product yield studies and cubic log scaling studies underway recognize that board-foot volumes deducted for defects such as shake or checks may still produce high quality chips. Included in cubic scaling is the wood volume outside the Scribner log scaling cylinder.

Chip yield from sawn logs is presented in figures 5, 6, and 7. It is expressed as pounds of ovendry chips:

(1) per cubic foot of gross log volume,
(2) per cubic foot of lumber output, and
(3) per thousand board feet, net Scribner scale, of logs.

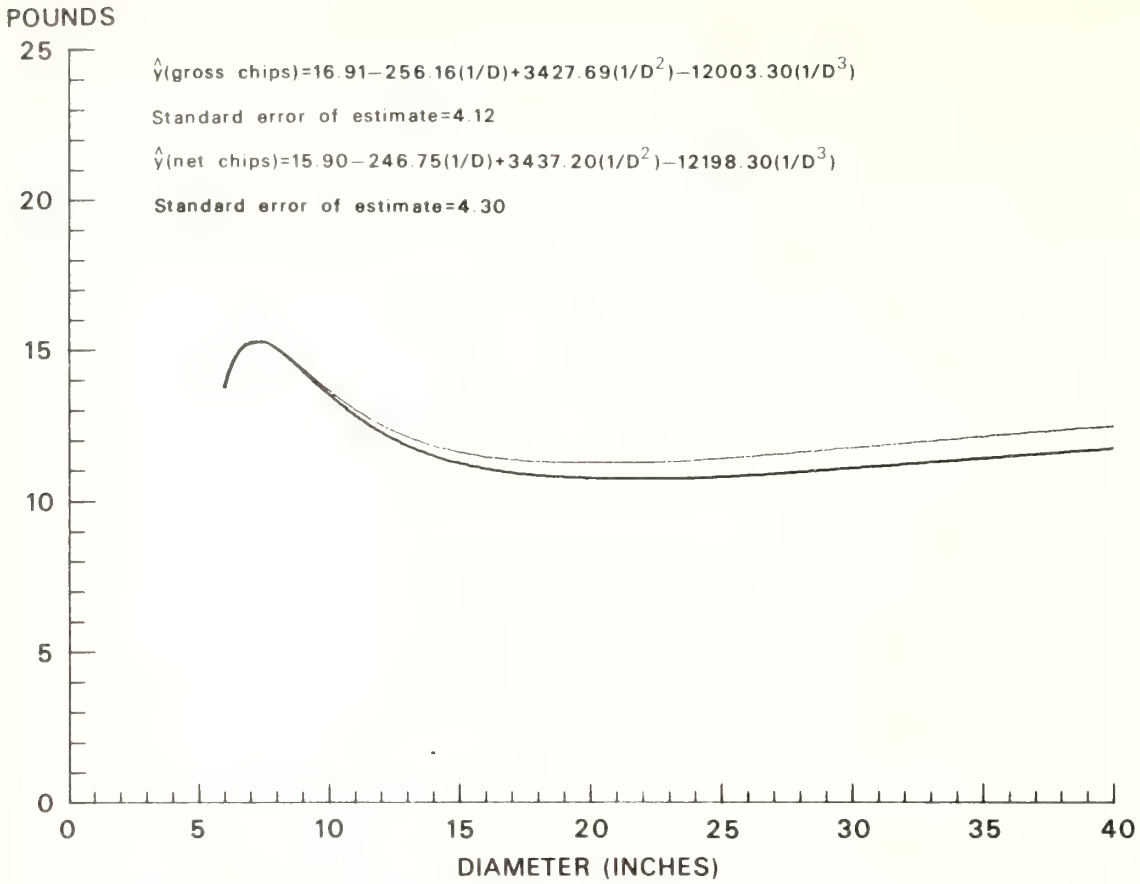

Figure 5.--Yields of ovendry chips per cubic foot of log input over diameter.

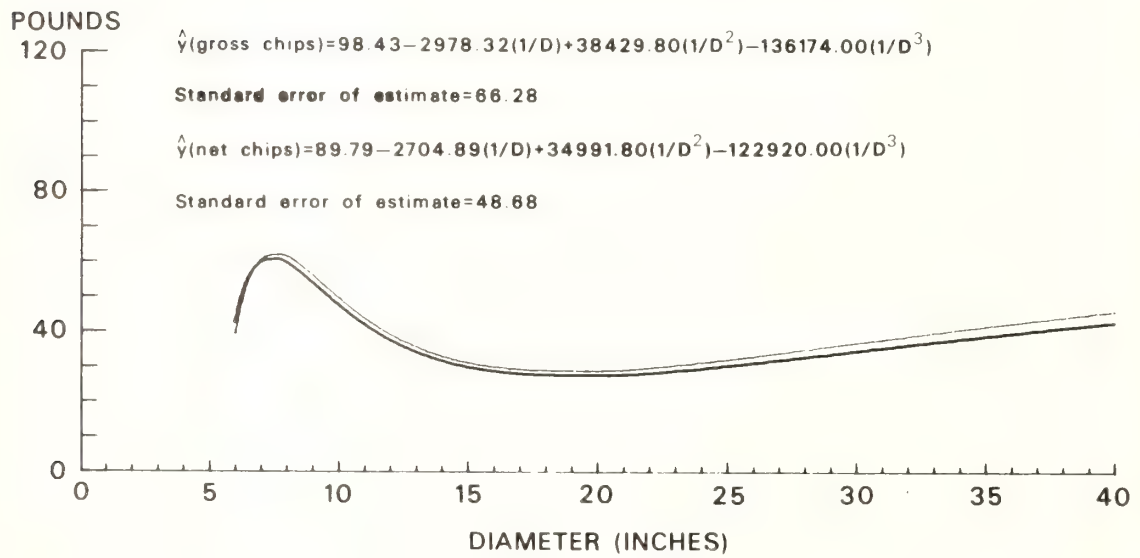

Figure 6.--Yields of ovendry chips per cubic foot of lumber output over diameter.

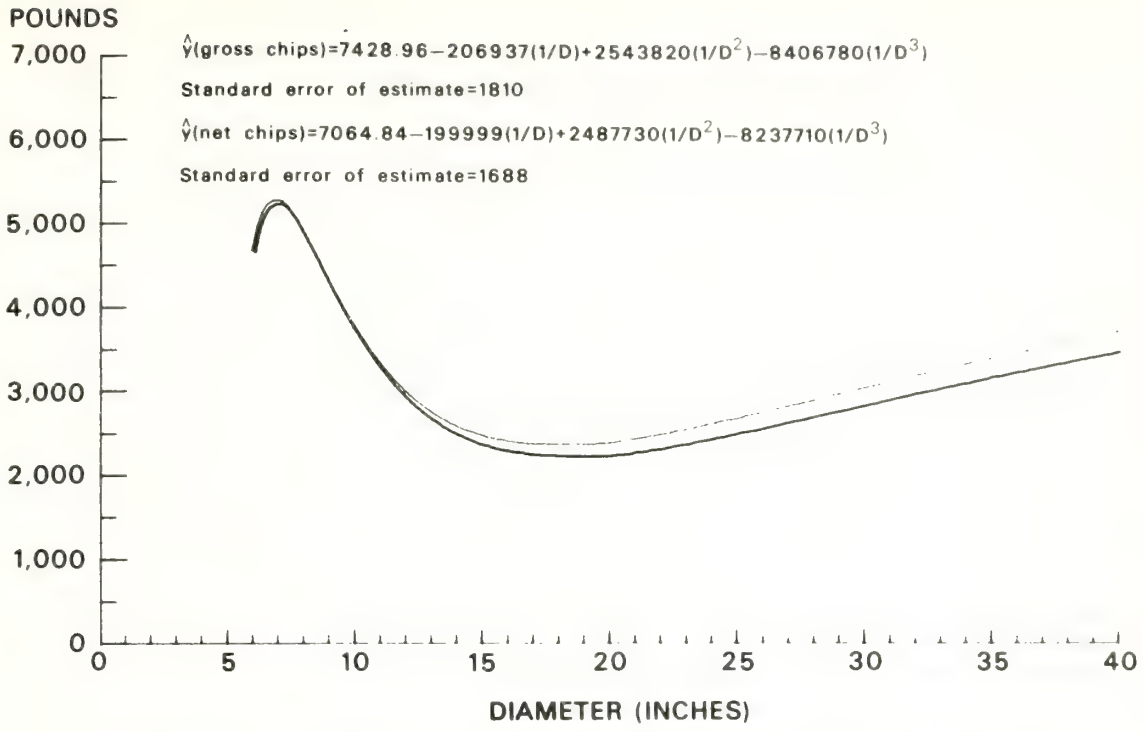

Figure 7.--Yields of ovendry chips per thousand board feet (net Scribner scale) of log input over diameter.

Chip yields expressed as pounds per cubic foot of log volume recognize the forest products industry trend to express mill input and product output in cubic feet. Likewise, chip yields, in terms of pounds per cubic foot of lumber, recognize the Alaska export market where cants are transported by ship. Knowledge of the lumber volume placed in a ship's hold can be used to estimate the amount of chips that resulted from sawing the lumber. Finally, chip yields expressed as pounds per thousand board feet of logs are used because log volume into mills is still generally expressed as Scribner scale.

The calculations to convert cubic volumes to weight for each log require a wood density value in pounds per cubic foot (green weight and green volume) and an average wood moisture content. The following example uses a density value of 53.7 pounds per cubic foot and a 105-percent moisture content to illustrate the calculations to estimate pounds of ovendry chips from an individual log. The log chosen for the example is the single 34-inch log in appendix table 8.

From appendix 1, table 8, determine that 134 cubic feet of gross chippable residue volume was produced from 215 cubic feet of sawn log volume.

Next, convert this cubic volume to green weight: (134 cubic feet) X (53.7 pounds per cubic foot of green density for western hemlock) = 7,196 pounds gross weight of chippable residue volume.

Convert green weight to ovendry weight using 105-percent average moisture content for western hemlock: (7,196 pounds of chips) ÷ (1 + $\frac{105}{100}$ moisture content) = 3,510 pounds, the ovendry weight of gross chippable residue volume.

Express pounds of ovendry chips on the per-unit basis noted earlier:

1. (3,510 pounds of ovendry chips) ÷ (215 cubic feet of log volume) = 16.3 pounds of ovendry chips per cubic foot of gross log volume.

2. (3,510 pounds of ovendry chips) ÷ (72 cubic feet of lumber recovered) = 48.7 pounds of ovendry chips per cubic foot of lumber output.

3. (3,510 pounds of ovendry chips) ÷ (740 board feet, net Scribner scale, of lumber) (1,000) = 4,743 pounds of ovendry chips per 1,000 board feet, net Scribner scale, of lumber.

Chip weight calculated in above examples is expected to overestimate actual production of suitable chips because certain wood rots, in the decay stage termed "typical," render coarse wood residue unsuitable for chips. Therefore, to estimate a net residue cubic volume suitable for chip production, Dr. James W. Kimmey[4] determined, during the sawing of each log, cubic volume of the rot, by type, in both the incipient and typical stages. These volumes have been used to adjust downward the calculated estimates of chippable residue volumes shown in figures 5, 6, and 7.

Note the shape of the curve in the lower diameters of figures 5, 6, and 7. The peak in the curve, at about 7 inches, was possible to identify because the curve form used was sensitive to this type of data variation. The product mix from small logs supports this curve. The 6- and 7-inch logs generally yielded a single 4- by 4-inch cant; thus, the proportion of chippable residue available from the 7-inch log was greater. Plotting individual log chip yields over diameter substantiates the curve form in the smaller diameters.

The proportion of lumber recovered increased from 8-inch to 15-inch logs, then remained fairly uniform to 20-inch logs. This is indicated by a decrease in the chip yield curves of figures 5, 6, and 7. In logs above 20 inches in diameter, a slight upward trend is evident, probably due to increased defect in larger logs, particularly in shake, which most frequently occurs in butt logs.

The chip yields presented in the curves of figures 5, 6, and 7 vary tremendously for individual logs within a diameter class. The standard errors are shown on the figures. The figure 5 standard error indicates a chip yield of pounds of ovendry chips per cubic foot of log input of 4.30 pounds. The reader should be aware of the variation when using the curves to predict chip yields of individual logs; however, diameter class averages can be expected to follow the curved relationship for reasonable size samples (i.e., probably in excess of 10 logs per diameter class).

[4]Forest pathologist, retired, U.S. Forest Service.

Consider, however, for discussion purposes, an example of the pounds of ovendry chips per cubic foot of logs sawn. From figure 5, the amount estimated for the 25-inch-diameter sawn logs on a gross cubic log volume basis, not accounting for decay, is about 11.3 pounds. When a reduction in gross cubic log volume is made for areas of decay not suitable for chipping, the pounds per cubic foot drops to about 10.8. This small drop in the chip weight estimate can have a considerable effect on an estimate of chip production. For example, from 2 million cubic feet of logs, approximately 1 million fewer pounds of ovendry chips are recoverable due to presence of decay not suitable for fiber production.

Woods Residue - Tree Utilization

There are increasing awareness and concern over the volume of residue developed during logging. Although this study was not designed to sample logging residue volume, the amounts by types are of interest and can generally be considered representative of similar areas and timber in southeast Alaska.

The top diameter utilization selected for this yield study was 8 inches. As can be seen in appendix table 18, 62 logs were bucked in the woods to 6- and 7-inch diameters.

The gross volume to total height of the 342 processed trees was 80,923[5] cubic feet. A total of 62,105 cubic feet was converted to sawn logs which produced 28,088 cubic feet of lumber. The total sawn log volume also includes 8,540 cubic feet of cull logs.

Table 5 presents the classes of woods residue that were identified and show calculated cubic volumes of each. Table 6 shows the average size of log components. Trees are grouped by 10-inch d.b.h. classes. The sawn log volume was 76.8 percent of the tree volume.

[5]U.S. Department of Agriculture, Forest Service. Sept. 1955. Agriculture Handbook No. 92.

Table 5.--Volume of logging residue as percentages of western hemlock tree volume[1] for southeast Alaska

D.b.h. class (inches)	Trees in sample	Average gross volume per tree	Sawn log volume	Broken logs		Long butts		Unused to 8-inch top		Top[2]	Total
				Trees with breaks	Volume	Trees with long butts	Volume	Trees with unused volume	Volume	Volume	
	Number	Cubic feet	Percent	Number	Percent	Number	Percent	Number	Percent	Percent	Percent
11.0-19.9	88	61.5	[illegible]	5	0.5	1	0.1	29	3.6	13.2	100
20.0-29.9	109	151.4	83.8	18	1.0	7	.9	70	3.1	11.2	100
30.0-39.9	88	305.7	83.1	41	2.5	17	4.3	69	3.9	6.2	100
40.0-49.9	48	533.4	69.3	27	4.5	16	9.9	40	3.6	12.8	100
50.0+	9	722.1	60.3	7	2.5	3	12.2	7	4.7	13.8	100
Total or weighted average	342	236.6	76.8	98	3.2	44	5.7	215	[3]3.6	10.8	100

[1] Without deductions for rot.

[2] Measured from the used top or 8-inch top to total height.

[3] Includes cull logs left in the woods.

Table 6.--*Average size of logging residue components from western hemlock for southeast Alaska*

D.b.h. average of class (inches)	Sawn logs		Broken logs		Long butts		Unused to 8-inch top	
	Length	Top diameter	Length	Small diameter	Length	Small diameter	Length	Large diameter
	Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches
16.5	65	7.9	9.2	10.6	4.3	11.0	10.4	9.8
24.3	86	9.5	7.7	14.3	8.9	20.9	13.2	10.5
34.0	101	12.8	11.6	16.4	11.8	28.5	17.6	13.3
44.0	112	14.5	11.3	20.9	17.1	33.8	22.1	15.4
52.4	114	19.9	18.8	25.4	22.1	38.7	26.6	19.4

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Appendix 1

Summary tables of recovery volumes by log grade and diameter classes, bucked or sawn-length logs, southeast Alaska--tables 7-12.

Table 7.--*Summary of log scale, lumber recovery, and cubic volumes by diameter classes--sawn-length, western hemlock Peeler grade logs*[1/] *for southeast Alaska*

Log scaling diameter (inches)	Number of Peeler grade logs	Log scale[1/]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2/]	Log	Lumber	Lumber recovery percent[3/]	Sawdust	Chippable residue
		- - - - -Board feet- - - - -				*- - - Cubic feet - - -*			*- - -Cubic feet- - -*	
25	1	750	610	821	135	99.69	68.85	69	9.19	21.65
26	0	--	--	--	--	--	--	--	--	--
27	0	--	--	--	--	--	--	--	--	--
28	1	950	880	1,082	123	132.21	89.61	68	12.51	30.09
29	0	--	--	--	--	--	--	--	--	--
30	0	--	--	--	--	--	--	--	--	--
31	0	--	--	--	--	--	--	--	--	--
32	1	920	820	975	119	126.25	81.77	65	10.70	33.78
Total	3	2,620	2,310	2,878	125	358.15	240.23	67	32.40	85.52

1/ As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

2/ Lumber tally as percentage of net scale volume.

3/ Lumber cubic volume as percentage of log cubic volume.

Table 8.--*Summary of log scale, lumber recovery, and cubic volumes by diameter classes--sawn-length, western hemlock No. 1 grade logs*[1] *for southeast Alaska*

Log scaling diameter (inches)	Number of No. 1 grade logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2]	Log	Lumber	Lumber recovery percent[3]	Sawdust	Chippable residue
		Board feet				*Cubic feet*			*Cubic feet*	
24	5	3,140	2,500	3,412	136	456.14	287.55	63	37.35	131.24
25	4	2,640	2,200	2,581	117	497.10	217.19	44	28.60	251.31
26	7	5,410	4,180	4,625	111	820.11	388.23	47	50.94	380.94
27	6	4,290	3,380	3,948	117	569.69	332.73	58	42.76	194.20
28	3	2,850	2,390	2,868	120	470.51	241.06	51	31.53	197.92
29	7	5,630	4,110	5,183	126	889.90	434.10	49	57.73	398.07
30	5	4,350	3,160	4,010	127	605.39	336.21	56	43.44	225.74
31	4	3,820	2,490	3,630	146	698.33	303.33	43	41.20	353.80
32	2	1,840	1,190	1,458	123	273.33	122.02	45	16.26	135.05
33	4	4,210	2,690	4,122	153	640.21	345.31	54	45.30	249.60
34	1	1,000	740	852	115	214.82	71.91	33	9.18	133.73
35	3	3,600	2,300	2,884	125	539.75	241.90	45	31.93	265.92
36	0	--	--	--	--	--	--	--	--	--
37	0	--	--	--	--	--	--	--	--	--
38	0	--	--	--	--	--	--	--	--	--
39	1	1,820	1,420	1,698	120	250.57	142.35	57	18.83	89.39
40	1	1,500	920	1,215	132	270.56	102.01	38	13.35	155.20
41	0	--	--	--	--	--	--	--	--	--
42	0	--	--	--	--	--	--	--	--	--
43	1	2,270	1,590	1,944	122	387.28	163.22	42	21.33	202.73
Total	54	48,370	35,260	44,430	126	7,583.69	3,729.12	49	489.73	3,364.84

[1] As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

[2] Lumber tally as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Table 9.--*Summary of log scale, lumber recovery, and cubic volume by diameter class--sawlength, western hemlock No. 2 grade logs*[1] *for southeast Alaska*

Log scaling diameter (inches)	Number of No. 2 grade logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2]	Log	Lumber	Lumber recovery percent[3]	Sawdust	Chippable residue
		Board feet				Cubic feet			Cubic feet	
14	40	5,750	5,480	6,302	115	1,106.06	526.89	48	71.24	507.93
15	50	8,950	8,570	9,642	113	1,618.14	807.73	50	108.25	702.16
16	62	12,900	11,870	13,253	112	2,329.70	1,109.30	48	148.59	1,071.81
17	47	10,940	9,900	11,178	113	1,936.54	933.42	48	126.37	876.75
18	46	12,560	10,980	12,175	111	2,086.02	1,019.64	49	136.07	930.31
19	47	13,560	11,420	13,993	123	2,188.99	1,173.98	54	155.01	860.00
20	43	15,550	12,880	15,062	117	2,516.43	1,260.56	50	169.80	1,086.07
21	35	13,110	10,750	12,744	119	2,072.31	1,067.33	52	141.80	863.18
22	38	16,750	13,550	15,876	117	2,719.85	1,331.03	49	175.60	1,213.22
23	26	11,280	7,970	10,268	129	1,684.21	860.35	51	114.49	709.37
24	28	14,450	10,840	12,966	120	2,226.00	1,085.85	49	144.44	995.71
25	27	15,890	10,650	12,563	118	2,382.56	1,053.19	44	139.06	1,190.31
26	18	10,210	7,720	9,174	119	1,458.31	768.13	53	102.43	587.75
27	17	11,010	8,140	9,671	119	1,575.96	808.94	51	108.15	658.87
28	11	8,020	5,630	7,643	136	1,125.66	637.76	57	86.64	401.26
29	6	4,250	3,450	2,384	69	631.21	200.53	32	26.31	404.37
30	8	5,820	4,180	4,514	108	822.07	381.03	46	48.77	392.27
31	10	7,710	5,230	6,031	115	1,295.06	503.69	39	67.65	723.72
32	3	2,940	1,700	2,078	122	435.79	174.59	40	23.13	238.07
33	1	690	490	540	110	120.21	45.34	38	6.08	68.79
34	2	2,000	1,300	2,269	175	364.21	189.81	52	25.32	149.08
35	0	--	--	--	--	--	--	--	--	--
36	1	810	700	875	125	125.76	73.32	58	9.82	42.62
37	0	--	--	--	--	--	--	--	--	--
38	0	--	--	--	--	--	--	--	--	--
39	1	1,120	590	816	138	136.16	68.55	50	8.93	58.68
Total	567	206,270	163,990	192,017	117	32,957.21	16,080.96	49	2,143.95	14,732.30

1/ As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

2/ Lumber tally as percentage of net scale volume.

3/ Lumber cubic volume as percentage of log cubic volume.

Table 10.--*Summary of log grade, lumber recovery, and cubic volumes by 1-inch diameter classes--same length, western hemlock-Sitka spruce No. 3 grade logs*[1] *for southeast Alaska*

Log scaling diameter (inches)	Number of No. 3 grade logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2]	Log	Lumber	Lumber recovery percent[3]	Sawdust	Chippable residue
		Board feet				Cubic feet			Cubic feet	
6	13	330	330	511	155	104.99	44.27	42	5.56	55.16
7	24	870	830	1,157	139	280.65	97.28	35	13.31	170.06
8	49	1,920	1,880	2,825	150	613.52	236.36	39	32.13	345.03
9	63	2,940	2,890	4,060	140	880.39	340.63	39	46.22	493.54
10	61	4,290	4,050	4,934	122	982.12	413.58	42	55.62	512.92
11	70	6,230	5,950	7,443	125	1,403.99	623.37	44	83.12	697.50
12	72	7,480	7,190	9,320	130	1,646.15	779.06	47	104.93	762.16
13	67	8,190	7,900	9,425	119	1,618.53	783.50	48	108.80	726.23
14	39	5,640	5,110	6,200	121	1,155.41	518.81	45	69.73	566.87
15	16	2,380	2,100	2,460	117	460.54	205.77	45	27.74	227.03
16	13	2,560	2,160	2,901	134	468.93	242.46	52	32.87	193.60
17	8	2,130	1,820	2,235	123	368.42	186.59	51	24.99	156.84
18	11	2,600	2,270	2,254	99	409.94	188.59	46	25.13	196.22
19	15	4,140	3,540	4,739	134	706.09	396.73	56	52.36	257.00
20	11	3,850	3,170	4,084	129	609.58	340.59	56	46.19	222.81
21	4	1,520	1,220	1,494	122	231.56	124.89	54	16.84	89.73
22	5	1,420	1,180	1,555	132	208.43	130.04	62	17.43	60.96
23	1	--	--	--	--	--	--	--	--	--
24	1	450	300	75	25	71.86	6.25	9	.83	64.78
25	1	1,150	540	642	119	153.81	53.92	35	7.04	92.85
26	1	620	210	591	281	79.56	49.82	63	6.65	23.09
27	1	890	340	595	175	128.05	49.41	39	6.61	71.63
28	--	--	--	--	--	--	--	--	--	--
29	1	610	230	362	157	83.98	30.39	36	4.03	49.56
Total	543	62,210	55,210	69,862	127	12,666.50	5,842.91	46	787.43	6,036.16

[1] Scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

[2] Lumber tally is percentage of net scale volume.

[3] Lumber recovery is percentage of log cubic volume.

Table 11.--*Summary of log scale, lumber recovery, and cubic volumes by diameter classes--saw-length, western hemlock cull logs for southeast Alaska*

Log scaling diameter (inches)	Number of cull logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2]	Log	Lumber	Lumber recovery percent[3]	Sawdust	Chippable residue
		- - - - -Board feet- - - - -				- - - Cubic feet - - -			- - -Cubic feet- - -	
9	1	40	--	26	--	14.65	2.26	15	.28	12.11
10	1	60	--	77	--	12.68	6.40	50	.89	5.39
11	1	80	--	69	--	20.11	5.80	29	.77	13.54
12	3	340	40	390	975	80.50	32.82	41	4.27	43.41
13	1	120	--	11	--	28.25	.81	3	.16	27.28
14	0	--	--	--	--	--	--	--	--	--
15	2	340	--	209	--	57.95	17.64	30	2.31	38.00
16	1	120	--	7	--	21.29	.50	2	.10	20.69
17	2	550	--	422	--	132.39	35.17	27	4.84	92.38
18	1	190	--	88	--	39.17	7.36	19	.98	30.83
19	3	930	--	546	--	151.52	45.44	30	6.17	99.91
20	4	1,210	--	686	--	220.45	57.47	26	7.68	155.30
21	5	1,760	--	551	--	289.42	46.20	16	6.23	236.99
22	6	2,420	130	1,188	914	368.97	99.28	27	13.37	256.32
23	3	1,550	--	1,044	--	260.59	87.27	33	11.79	161.53
24	7	3,420	140	1,636	1,169	526.31	136.48	26	18.26	371.57
25	3	1,840	--	543	--	321.97	44.55	14	6.54	270.88
26	6	3,380	--	1,942	--	512.93	162.49	32	21.69	328.75
27	3	1,780	--	824	--	256.45	69.39	27	8.89	178.17
28	6	4,010	--	1,971	--	517.81	165.38	32	21.86	330.57
29	6	4,030	--	1,232	--	644.20	103.34	16	13.64	527.22
30	6	4,420	--	1,093	--	607.65	90.37	15	12.56	504.72
31	3	2,040	--	352	--	307.12	29.25	10	4.04	273.83
32	5	4,600	--	1,547	--	685.20	130.10	19	15.95	539.15
33	3	2,940	--	1,886	--	374.71	158.39	42	20.97	195.35
34	6	4,900	--	2,778	--	710.78	231.46	33	31.08	448.24
35	3	3,060	360	1,784	496	576.35	149.66	26	19.78	406.91
36	1	1,150	--	1,019	--	188.97	84.76	45	11.63	92.58
37	2	2,320	--	1,090	--	367.78	92.08	25	11.97	263.73
38	0	--	--	--	--	--	--	--	--	--
39	1	980	--	322	--	125.30	27.36	22	3.34	94.60
40	0	--	--	--	--	--	--	--	--	--
41	0	--	--	--	--	--	--	--	--	--
42	1	1,010	--	901	--	118.22	74.82	63	10.31	33.09
Total	96	55,590	670	26,234	3,916	8,539.69	2,194.30	26	292.35	6,053.04

1/ As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

2/ Lumber tally as percentage of net scale volume.

3/ Lumber cubic volume as percentage of log cubic volume.

Table 12.--Summary of log scale, lumber recovery, and cubic volumes by diameter classes--all saw-length, western hemlock logs combined, for southeast Alaska

Log scaling diameter (inches)	Number of logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2]	Log	Lumber	Lumber recovery percent[3]	Sawdust	Chippable residue
		Board feet				Cubic feet			Cubic feet	
6	11	330	330	511	155	104.99	44.27	42	5.56	55.16
7	24	870	830	1,157	139	280.65	97.28	35	13.31	170.06
8	49	1,920	1,880	2,825	150	613.52	236.36	39	32.13	345.03
9	64	2,980	2,890	4,086	141	895.04	342.89	38	46.50	505.65
10	62	4,350	4,050	5,011	124	994.80	419.98	42	56.51	518.31
11	71	6,310	5,950	7,512	126	1,424.10	629.17	44	83.89	711.04
12	75	7,820	7,230	9,710	134	1,726.65	811.88	47	109.20	805.57
13	68	8,310	7,900	9,436	119	1,646.78	784.31	48	108.96	753.51
14	79	11,390	10,590	12,502	118	2,261.47	1,045.70	46	140.97	1,074.80
15	68	11,670	10,670	12,311	115	2,136.63	1,031.14	48	138.30	967.19
16	76	15,580	14,030	16,161	115	2,819.92	1,352.26	48	181.56	1,286.16
17	57	13,620	11,720	13,835	118	2,437.35	1,155.18	47	156.20	1,125.97
18	58	15,350	13,250	14,517	110	2,535.13	1,215.59	48	162.18	1,157.36
19	63	18,630	14,960	19,278	129	3,046.60	1,616.15	53	213.54	1,216.91
20	58	20,610	16,050	19,832	124	3,346.46	1,658.62	50	223.67	1,464.17
21	44	16,390	11,970	14,789	124	2,593.29	1,238.42	48	164.92	1,189.95
22	47	20,590	14,860	18,619	125	3,297.25	1,560.35	47	206.40	1,530.50
23	29	12,830	7,970	11,312	142	1,944.80	947.62	49	126.28	870.90
24	41	21,460	13,780	18,089	131	3,280.31	1,516.13	46	200.88	1,563.30
25	37	22,270	14,000	17,150	122	3,455.13	1,437.70	42	190.48	1,826.95
26	32	19,620	12,110	16,332	135	2,870.91	1,368.67	48	181.41	1,320.83
27	27	17,970	11,860	15,038	127	2,530.15	1,260.97	50	166.41	1,102.77
28	21	15,830	8,900	13,564	152	2,246.19	1,133.81	50	152.54	959.84
29	20	14,520	7,790	9,161	118	2,249.29	768.46	34	101.71	1,379.12
30	19	14,590	7,340	9,617	131	2,035.11	807.61	40	104.77	1,122.73
31	17	13,570	7,720	10,013	130	2,300.51	836.27	36	112.89	1,351.35
32	11	10,300	3,710	6,058	163	1,520.57	508.48	33	66.04	946.05
33	8	7,840	3,180	6,548	206	1,135.13	549.04	48	72.35	513.74
34	9	7,900	2,040	5,899	289	1,289.81	493.18	38	65.58	731.05
35	6	6,660	2,660	4,668	175	1,116.10	391.56	35	51.71	672.83
36	2	1,960	700	1,894	271	314.73	158.08	50	21.45	135.20
37	2	2,320	--	1,090	--	367.78	92.08	25	11.97	263.73
38	0	--	--	--	--	--	--	--	--	--
39	3	3,920	2,010	2,836	141	512.03	238.26	47	31.10	242.67
40	1	1,500	920	1,215	132	270.56	102.01	38	13.35	155.22
41	0	--	--	--	--	--	--	--	--	--
42	1	1,010	--	901	--	118.22	74.82	63	10.31	33.09
43	1	2,270	1,590	1,944	122	387.28	163.22	42	21.33	202.73
Total	1,261	375,060	257,440	335,421	130	62,105.24	28,087.52	45	3,746.36	30,271.36

[1] As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

[2] Lumber tally as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Appendix 2

Summary tables of recovery volumes by log grade and diameter classes, rafted or woods-length logs, southeast Alaska--tables 13-18.

Table 13.--*Summary of log scale, lumber recovery, and cubic volumes by diameter classes--woods-length, western hemlock Peeler grade logs*[1] *for southeast Alaska*

Log scaling diameter (inches)	Number of Peeler grade logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2]	Log	Lumber	Lumber recovery percent[3]	Sawdust	Chippable residue
		Board feet				*Cubic feet*			*Cubic feet*	
26	1	1,250	1,060	949	90	233.51	80.11	34	10.35	143.05
27	0	--	--	--	--	--	--	--	--	--
28	1	1,460	1,100	1,514	138	254.82	126.95	50	16.99	110.88
29	0	--	--	--	--	--	--	--	--	--
30	1	1,640	1,460	2,212	152	337.72	183.63	54	25.36	128.73
Total	3	4,350	3,620	4,675	129	826.05	390.69	47	52.70	382.66

[1] As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

[2] Lumber tally as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Table 14.--*Summary of log scale, lumber recovery, and cubic volumes by diameter classes--woods-length, western hemlock No. 1 grade logs*[1] *for southeast Alaska*

Log scaling diameter (inches)	Number of No. 1 grade logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2]	Log	Lumber	Lumber recovery percent[3]	Sawdust	Chippable residue
		- - - - - *Board feet* - - - - -				- - - *Cubic feet* - - -			- - - *Cubic feet* - - -	
24	4	3,690	3,020	4,057	134	900.54	341.65	38	44.38	514.51
25	2	2,300	1,880	2,155	115	463.24	180.79	39	23.35	259.10
26	3	3,190	2,250	3,281	146	598.44	274.98	46	36.10	287.36
27	2	2,740	2,130	3,390	159	585.85	282.80	48	38.83	264.22
28	3	3,500	2,400	2,773	116	656.83	233.12	35	30.43	393.28
29	4	6,080	3,710	3,698	100	1,269.88	310.80	24	40.92	918.16
30	0	--	--	--	--	--	--	--	--	--
31	3	4,270	2,140	3,192	149	867.60	268.13	31	35.02	564.45
32	2	3,040	2,140	2,787	130	599.36	232.76	39	31.02	335.58
33	3	5,390	3,720	4,841	130	1,199.20	406.92	34	53.78	738.50
34	0	--	--	--	--	--	--	--	--	--
35	0	--	--	--	--	--	--	--	--	--
36	0	--	--	--	--	--	--	--	--	--
37	0	--	--	--	--	--	--	--	--	--
38	1	1,070	380	816	215	132.76	68.55	52	8.93	55.28
39	2	3,640	2,360	2,921	124	489.04	244.53	50	32.48	212.03
40	1	1,500	670	1,215	181	270.56	102.01	38	13.35	155.20
41	0	--	--	--	--	--	--	--	--	--
42	0	--	--	--	--	--	--	--	--	--
43	0	--	--	--	--	--	--	--	--	--
44	1	2,410	1,340	1,944	145	394.27	163.22	41	21.33	209.72
Total	31	42,820	28,140	37,070	132	8,427.57	3,110.26	37	409.92	4,907.39

[1] As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

[2] Lumber tally as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Table 15.--Average [illegible] log scale, lumber recovery, and cubic volumes by diameter classes--[illegible] log-length, western hemlock [illegible] grade logs[1] for southeast Alaska

Log scaling diameter (inches)	Number of No. 2 grade logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2]	Log	Lumber	Lumber recovery percent[3]	Sawdust	Chippable residue
		Board feet				Cubic feet			Cubic feet	
14	20	6,940	6,460	8,369	130	1,764.37	699.46	40	94.88	970.03
15	32	12,450	11,150	13,237	119	2,763.89	1,108.61	40	148.42	1,506.86
16	20	8,690	7,830	10,208	130	1,933.80	854.94	44	114.69	964.17
17	17	8,480	7,870	10,061	128	1,818.88	844.19	46	112.23	862.46
18	25	14,640	11,800	15,942	135	3,108.12	1,335.08	43	178.03	1,595.01
19	17	10,610	8,250	10,931	132	2,086.04	915.33	44	121.85	1,048.86
20	14	11,310	8,710	12,249	141	2,228.14	1,024.73	46	137.19	1,066.22
21	22	17,710	14,270	18,322	128	3,772.56	1,532.75	41	204.98	2,034.83
22	14	11,750	9,400	11,642	124	2,159.77	978.92	45	128.33	1,052.52
23	8	8,140	6,490	8,149	126	1,570.44	684.21	44	89.80	796.43
24	13	14,530	11,380	13,663	120	2,567.14	1,145.25	45	151.17	1,270.72
25	7	6,780	4,800	6,895	144	1,203.17	578.09	48	77.20	547.88
26	4	5,640	3,690	5,026	136	1,154.40	419.55	36	56.44	678.41
27	6	7,810	4,940	7,087	143	1,203.56	593.06	49	79.27	531.23
28	4	6,230	4,010	5,189	129	1,042.53	436.45	42	56.50	549.58
29	4	6,270	3,940	6,343	161	1,027.55	532.20	52	70.39	424.96
30	3	4,560	3,040	3,935	129	778.75	331.77	43	42.56	404.42
31	2	2,300	1,910	1,922	101	335.61	160.24	48	21.71	153.66
32	0	--	--	--	--	--	--	--	--	--
33	2	3,720	1,670	1,716	103	592.52	143.45	24	19.06	430.01
34	0	--	--	--	--	--	--	--	--	--
35	1	1,420	770	1,481	192	240.08	124.15	52	16.37	99.56
Total	235	169,980	132,380	172,367	130	33,351.32	14,442.43	43	1,921.07	16,987.82

[1] As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

[2] Lumber tally as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Table 16.--*Summary of log scale, lumber recovery, and cubic volumes by diameter classes--woods-length, western hemlock No. 3 grade logs*[1] *for southeast Alaska*

Log scaling diameter (inches)	Number of No. 3 grade logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2]	Log	Lumber	Lumber recovery percent[3]	Sawdust	Chippable residue
		Board feet				*Cubic feet*			*Cubic feet*	
6	28	4,970	4,550	5,413	119	1,548.58	455.84	29	60.43	1,032.31
7	34	3,230	3,080	3,941	128	917.86	330.51	36	44.90	542.45
8	53	5,730	5,400	8,329	154	1,744.42	697.41	40	93.53	953.48
9	49	5,850	5,410	7,997	148	1,560.65	668.48	43	89.73	802.44
10	38	5,680	5,300	6,853	129	1,365.22	571.58	42	78.77	714.87
11	45	8,930	7,840	11,171	142	2,229.76	932.55	42	126.45	1,170.76
12	44	9,480	8,520	12,936	152	2,293.05	1,085.52	47	143.82	1,063.71
13	32	7,420	6,800	9,543	140	1,636.79	796.30	49	108.32	732.17
14	23	5,450	4,550	7,473	164	1,241.50	624.35	50	83.85	533.30
15	9	2,010	1,410	2,457	174	424.68	205.85	48	27.60	191.23
16	5	2,000	1,690	2,335	138	415.87	194.58	47	26.35	194.94
17	8	2,680	1,950	2,576	132	470.34	215.57	46	28.64	226.13
18	4	2,100	1,410	2,777	197	427.93	231.94	54	30.62	165.37
19	11	6,220	4,890	7,529	154	1,166.98	629.08	54	84.66	453.24
20	3	1,920	1,090	2,398	220	361.92	201.42	56	26.37	134.13
21	3	2,280	1,390	2,099	151	395.69	175.91	44	23.37	196.41
22	1	1,320	1,030	1,518	147	185.62	127.74	69	16.49	41.39
23	2	1,320	720	1,428	198	203.03	119.33	59	16.20	67.50
24	1	350	190	301	158	53.78	25.30	47	3.29	25.19
25	0	--	--	--	--	--	--	--	--	--
26	1	820	540	987	183	115.48	82.43	71	11.09	21.96
27	0	--	--	--	--	--	--	--	--	--
28	0	--	--	--	--	--	--	--	--	--
29	1	1,370	460	610	133	188.95	51.48	27	6.67	130.80
30	0	--	--	--	--	--	--	--	--	--
31	1	890	480	698	145	118.94	57.59	48	8.14	53.21
Total	396	82,020	68,700	101,369	148	19,067.04	8,480.76	44	1,139.29	9,446.99

[1] As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

[2] Lumber tally as percentage of net scale volume.

[3] Lumber cubic volume as percentage of log cubic volume.

Table 17.--Summary of log scale, lumber tally, and cubic volume by diameter classes--Scale-length, western hemlock cull logs from Chatham Area, Alaska

Log scaling diameter (inches)	Number of cull logs	Log scale[1]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2]	Log	Lumber	Lumber recovery percent[3]	Sawdust	Chippable residue
		Board feet				Cubic feet			Cubic feet	
8	1	30	--	45	--	8.84	3.84	43	.48	4.52
9	1	100	--	90	--	28.86	7.41	26	1.10	20.35
10	0	--	--	--	--	--	--	--	--	--
11	1	500	--	122	--	101.33	9.90	10	1.48	89.95
12	0	--	--	--	--	--	--	--	--	--
13	0	--	--	--	--	--	--	--	--	--
14	1	170	--	93	--	35.91	7.70	21	1.09	27.12
15	0	--	--	--	--	--	--	--	--	--
16	1	180	--	114	--	28.41	9.54	34	1.25	17.62
17	2	530	--	368	--	88.80	30.74	35	4.13	53.93
18	2	1,390	--	1,286	--	217.77	108.18	50	14.02	95.57
19	2	1,960	--	1,203	--	348.80	100.78	29	13.26	234.76
20	1	560	--	420	--	84.71	35.39	42	4.79	44.53
21	2	1,440	--	831	--	260.81	69.07	26	9.43	182.31
22	4	3,050	450	2,311	514	547.28	194.24	35	25.51	327.53
23	4	3,440	210	1,264	602	559.74	105.24	19	14.26	440.24
24	2	1,560	--	768	--	232.28	64.26	28	8.58	159.44
25	5	5,120	--	2,515	--	866.33	207.08	24	28.80	630.45
26	0	--	--	--	--	--	--	--	--	--
27	1	1,880	--	117	--	420.98	9.43	2	1.50	410.05
28	1	1,160	--	436	--	162.72	37.14	23	4.71	120.87
29	4	3,720	--	2,012	--	650.69	166.56	26	23.52	460.61
30	2	3,280	--	358	--	648.32	30.01	5	3.91	614.40
31	2	2,930	--	1,653	--	475.76	139.79	29	16.90	319.07
32	1	1,470	--	316	--	220.67	25.46	12	3.91	191.30
33	1	1,960	--	1,733	--	291.54	145.66	50	18.82	127.06
34	1	2,000	--	1,885	--	360.92	155.96	43	21.93	183.03
Total	42	38,430	660	19,940	3,021	6,641.47	1,663.38	25	223.38	4,754.71

1/ As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

2/ Lumber tally as percentage of net scale volume.

3/ Lumber cubic volume as percentage of log cubic volume.

Table 18.--*Summary of log scale, lumber recovery, and cubic volume by diameter classes--all species-length, western hemlock logs combined, for Southeast Alaska*

Log scaling diameter (inches)	Number of logs	Log scale[1/]		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery percent[2/]	Log	Lumber	Lumber recovery percent[3/]	Sawdust	Chippable residue
		Board feet				*Cubic feet*			*Cubic feet*	
6	28	4,970	4,550	5,413	119	1,548.58	455.84	29	60.43	1,032.31
7	34	3,230	3,080	3,941	128	917.86	330.51	36	44.90	542.45
8	54	5,760	5,400	8,374	155	1,753.26	701.25	40	94.01	958.00
9	50	5,950	5,410	8,087	149	1,589.51	675.89	43	90.83	822.79
10	38	5,680	5,300	6,853	129	1,365.22	571.58	42	78.77	714.87
11	46	9,430	7,840	11,293	144	2,331.09	942.45	40	127.93	1,260.71
12	44	9,480	8,520	12,936	152	2,293.05	1,085.52	47	143.82	1,063.71
13	32	7,420	6,800	9,543	140	1,636.79	796.30	49	108.32	732.17
14	44	12,560	11,010	15,935	145	3,041.78	1,331.51	44	179.82	1,530.45
15	41	14,460	12,560	15,694	125	3,188.57	1,314.46	41	176.02	1,698.09
16	26	10,870	9,520	12,657	133	2,378.08	1,059.06	45	142.29	1,176.73
17	27	11,690	9,820	13,005	132	2,378.02	1,090.50	46	145.00	1,142.52
18	31	18,130	13,210	20,005	151	3,753.82	1,675.20	45	222.67	1,855.95
19	30	18,790	13,140	19,663	150	3,601.82	1,645.19	46	219.77	1,736.86
20	18	13,790	9,800	15,067	154	2,674.77	1,261.54	47	168.35	1,244.88
21	27	21,430	15,660	21,252	136	4,429.06	1,777.73	40	237.78	2,413.55
22	19	16,120	10,880	15,471	142	2,892.67	1,300.90	45	170.33	1,421.44
23	14	12,900	7,420	10,841	146	2,333.21	908.78	39	120.26	1,304.17
24	20	20,130	14,590	18,789	129	3,753.74	1,576.46	42	207.42	1,969.86
25	14	14,200	6,680	11,565	173	2,532.74	965.96	38	129.35	1,437.43
26	9	10,900	7,540	10,243	136	2,101.83	857.07	41	113.98	1,130.78
27	9	12,430	7,070	10,594	150	2,210.39	885.29	40	119.60	1,205.50
28	9	12,350	7,510	9,912	132	2,116.90	833.66	39	108.63	1,174.61
29	13	17,440	8,110	12,663	156	3,137.07	1,061.04	34	141.50	1,934.53
30	6	9,480	4,500	6,505	145	1,764.79	545.41	31	71.83	1,147.55
31	8	10,390	4,530	7,465	165	1,797.91	625.75	35	81.77	1,090.39
32	3	4,510	2,140	3,103	145	820.03	258.22	31	34.93	526.88
33	6	11,070	5,390	8,290	154	2,083.26	696.03	33	91.66	1,295.57
34	1	2,000	--	1,885	--	360.92	155.96	43	21.93	183.03
35	1	1,420	770	1,481	192	240.08	124.15	52	16.37	99.56
36	0	--	--	--	--	--	--	--	--	--
37	0	--	--	--	--	--	--	--	--	--
38	1	1,070	380	816	215	132.76	68.55	52	8.93	55.28
39	2	3,640	2,360	2,921	124	489.04	244.53	50	32.48	222.03
40	1	1,500	670	1,215	181	270.56	102.01	38	13.35	155.20
41	0	--	--	--	--	--	--	--	--	--
42	0	--	--	--	--	--	--	--	--	--
43	0	--	--	--	--	--	--	--	--	--
44	1	2,410	1,340	1,944	145	394.27	163.22	41	21.33	209.72
Total	707	337,600	233,500	335,421	144	68,313.45	28,087.52	41	3,746.38	36,479.17

[1/] As scaled and graded by Forest Service check scaler according to the Puget Sound Log Scaling and Grading Bureau rules.

[2/] Lumber tally as percentage of net scale volume.

[3/] Lumber cubic volume as percentage of log cubic volume.

USGPO 796-242

Woodfin, Richard O., Jr., and Thomas A. Snellgrove
1976. Western hemlock in southeast Alaska--utilization, lumber recovery, and chip yield. USDA For. Serv. Res. Pap. PNW-208, 33 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Lumber recovery from western hemlock from southeast Alaska National Forest land is presented with cubic volume yields, cull log lumber recovery, estimates of chippable wood, and logging residue from sample trees.

KEYWORDS: Western hemlock, *Tsuga heterophylla*, wood utilization, lumber yield studies, sawmill recovery studies, log grading, cubic volume measure, chip production, southeast Alaska.

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1976
USDA FOREST SERVICE RESEARCH PAPER PNW-209

Code-A-Site:

A System for Inventory of Dispersed Recreational Sites in Developed Areas, Back Country, and Wilderness

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PORTLAND, OREGON

About the Authors

John C. Hendee, Roger N. Clark, and Mack L. Hogans are recreation research project leader, research social scientist, and research forester, respectively, Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

During this research, Dan Wood and Russell W. Koch were graduate research assistants at the College of Forest Resources, University of Washington, Seattle. Dan Wood is now recreation planner, Bureau of Land Management, U.S. Department of the Interior, Canon City, Colorado.

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CODE-A-SITE: A SYSTEM FOR INVENTORY OF DISPERSED RECREATIONAL SITES IN ROADED AREAS, BACK COUNTRY, AND WILDERNESS

Reference Abstract

Hendee, John C., Roger N. Clark, Mack L. Hogans, Dan Wood, and Russell W. Koch.
1976. Code-A-Site: A system for inventory of dispersed recreational sites in roaded areas, back country, and wilderness. USDA For. Serv. Res. Pap. PNW-209, 33 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Code-A-Site is a system for inventorying dispersed recreation sites that are established by users along forest roads, in back country, or in wilderness. The system uses edge-punch cards and needle-sorting methods for recording, storing, and retrieving basic site information such as location, characteristics, available resources, activities, and impacts.

KEYWORDS: Recreation, recording methods (data), dispersed recreation, inventory, carrying capacity, wilderness, environmental impacts.

RESEARCH SUMMARY

Research Paper PNW-209

1976

Code-A-Site is a system for inventorying dispersed recreation sites on forest roads, in back country, or wilderness. Dispersed sites in these settings have usually been established by impromptu use of recreationists but are important to management since they are the focal point for considerable recreation activity. Code-A-Site uses edge-punch cards for recording and storing basic information about dispersed sites for subsequent retrieval as needed for planning, management, and research purposes. Use of edge-punch cards and needle-sorting methods facilitates easy summary and analysis of data at field levels. Code-A-Site is designed for field use but provides opportunity for transfer of data to centralized computer storage and retrieval systems if desired.

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PART 1. AN INTRODUCTION TO CODE-A-SITE

The Need for Campsite Information

The management of any natural resource depends on adequate information about key variables. This is as true for the recreation resource as it is for timber, forage, water, wildlife, or scenery. Recreational sites, whether established through design and planning by managers or by impromptu use by forest visitors, are a focal point for recreational use and related environmental and social impacts[1/] (Brown and Schomaker 1974, McCurdy and Hartman 1974). Much recreational activity focuses about the site--eating, working, playing, and camping overnight.[2/] The location of sites determines where recreational impacts will concentrate--and the facilities and other attributes of the site are a strong influence on the activities that will take place. Thus, inventory data about the number, character, and location of recreational sites may be useful for dispersed recreational planning and management and for research on their use.

Dispersed camping on roaded forest land takes place in numerous impromptu campsites established by the public. Code-A-Site is a system for inventorying, storing, and retrieving information about such sites. (Courtesy Mack L. Hogans, personal photograph)

1/ Robert E. Pfister and Robert E. Frenkel. Dec. 1974. Field investigations of river use within the wild river area of the Rogue River, Oregon. Interim report submitted to Oregon Marine Board.

2/ A study of use at roadless high lakes indicates that 64 percent of nontrail time is spent in camp and 20 percent of the remaining time is spent at the adjacent (lake) attraction. See John C. Hendee, Roger N. Clark, and Thomas E. Dailey (1974) "Fishing and Other Recreation Behavior at Roadless High-Mountain Lakes: Some Implications for Resource Management." Unpublished paper presented to American Fisheries Society annual meeting, Honolulu, Hawaii, 27 p., mimeogr. Available from the authors, 4507 University Way N.E., Seattle, Wash. 98105. Other studies indicating the large proportion of time spent at campsites are reported by Alden (1965) and King (1965).

Dispersed recreation is now receiving more attention by managers. Lloyd and Fischer (1972) indicate it is the fastest growing recreation use in the National Forests; logic would indicate similar land is likewise affected. In roaded forest areas, dispersed recreation is a major means to the realization of multiple use values from lands incurring heavy timber harvest (Hendee 1974).

This paper describes Code-A-Site, a system for inventorying dispersed recreation sites along forest roads, in back country, and wilderness; it also discusses storage of this basic information for subsequent retrieval and use for planning, management, and research purposes. Part 2 is a codebook of instructions for collecting site information in the field.

Code-A-Site is proposed as a continuing inventory system enabling managers to monitor changes in sites and the creation of new sites over time. The system consists of (1) codebook guidelines for recording basic information about the recreational site--its location, facilities, natural attributes, impacts, etc., and (2) printed edge-punch cards on which the information can be stored for subsequent retrieval by needle-sorting methods. The use of edge-punch cards and needle-sorting methods is a well-established method for handling data; this system is fully operational at field levels where computer skills and equipment may not exist. However, there is potential for computers to store and retrieve Code-A-Site data or to tie the data into other computerized inventory systems.

Relationship of Code-A-Site to Other Inventory Systems

Code-A-Site is related to some objectives and capabilities of other inventory systems. It is related to the Forest Service's "Recreation Information Management System" (RIM), which is used to describe opportunities for recreation (USDA Forest Service 1968, 1969-74) and sample their use, primarily for computerized summaries of statistics at National Forest, regional, and national levels. Code-A-Site differs from RIM in several ways. Code-A-Site uses edge-punch cards to facilitate local field use. Code-A-Site focuses on opportunities for dispersed recreation, most of which are impromptu sites established by visitors rather than by the planning and design of managers. These sites are common on forest roads and in wilderness and back country and are not generally included in the RIM system. RIM recognizes some road occupancy spots that are heavily used and have been accorded official status by signs and garbage collection. But RIM does not inventory the many impromptu sites in dispersed areas that have no facilities but which are nevertheless a focal point for recreational use. However, information collected by Code-A-Site could be directly incorporated into RIM if desired.

The Total Resource Inventory system (TRI) of Region 6 of the U.S. Forest Service might also incorporate Code-A-Site data (USDA Forest Service 1960-74). The TRI system is a comprehensive compilation of resource data keyed to geographic location by legal description.

Dispersed recreational sites, though not officially recognized by the managing agencies, are a focal point for a variety of activities. (Courtesy Mack L. Hogans, personal photograph)

The National Forest Recreation Survey (NFRS), begun in 1959, bears some relationship to Code-A-Site. The NFRS was a systematic inventory by the Forest Service of all "existing" and "potential" developed outdoor recreation sites including location, suitable activities, access, ecological data, and judgments about site qualities. In field tests we found that some sites, originally identified by NFRS but never officially developed, had become established by impromptu recreational use and turned up in our Code-A-Site inventory.

The Bureau of Land Management's (U.S. Department of the Interior) extensive phase inventory, "Recreation Inventory System" (RIS), is similar in many respects to the Forest Service RIM system (U.S. Department of the Interior, Bureau of Land Management 1972). However, RIS is not a computer-oriented process; it relies basically on forms, files, and overlays for storing information on recreational resources. Code-A-Site data could easily fit into this broad system.

There may be other resource inventory systems that are related to Code-A-Site. However, our review of existing systems indicates that *Code-A-Site fills a need of managers at this time for an easy-to-use system for inventory and retrieval of information about dispersed recreation sites.* The system is designed to provide *basic site-oriented descriptive information at whatever level of specificity is desired by on-the-ground managers.* This information can be entered then, if desired, into any of the broader centralized systems such as RIM or RIS when they are extended to cover dispersed settings. Code-A-Site has sufficient flexibility to allow incorporation of special symbols to tie it to other systems.

Potential Use of Code-A-Site Data

With Code-A-Site data, managers, planners, and researchers will be able to answer many questions about the current status of dispersed sites and the potential effects of future use and management on the opportunities which are available. Following are some sample questions which seem basic to dispersed recreation management, planning, and research and can be answered with information summarized from Code-A-Site inventories.

1. How many and what kind of dispersed recreational sites exist on a particular road system, in back country, or in a wilderness unit? (With this data managers can evaluate the potential impact of road or trail closure on established recreational use.)

2. What is the overnight capacity of the area without forcing development of additional impromptu campsites? (Carrying capacity considerations require this data.)

3. What proportion of sites have sustained different degrees of environmental impact? (Managers might want to carefully inspect sites that are identified in the inventory as having been heavily impacted.)

4. What are the locations of sites that offer particular kinds of experiences? for example, for solitude, large parties, different activities such as motorbike riding, fishing, or berrypicking. (This may be useful for responding to recreationists' requests for information about where they might find certain kinds of sites.)

Receptionists at Ranger Districts are often asked by the public about camping and recreational opportunities. Code-A-Site data can help receptionists direct visitors to the kinds of opportunity they desire. Here a Mount Baker-Snoqualmie National Forest receptionist uses Code-A-Site data to inform a recreationist about a dispersed site. (Courtesy Mack L. Hogans, personal photograph)

5. Which sites have shortages of critical resources for different uses; e.g., water, firewood, forage, tent space? (Alternative sites may be needed.)

6. Which sites have management problems or need work? Where are they, and what is the problem? This is essential information for managers' work plans. There is an obvious danger here of overresponse--notations that, if followed, would "upgrade" or close every site, thus changing the opportunities the area affords. On the other hand, prevailing management direction and philosophy in the administrative unit govern these decisions--Code-A-Site merely provides a tool to help the decisionmaker gather information on dispersed sites, including an inventory of work deemed necessary on each site to protect resources or serve users.

Many dispersed recreationists prefer clearcut settings because of the access afforded by spur roads and the more abundant sunshine, berries, firewood, open vistas, trailbike opportunities, and other attractions not always present in heavy forest. (Courtesy Mack L. Hogans, personal photograph)

7. What proportion of the sites fall within certain standards that might be established to control capacity, quality of experience, or environmental and social impacts? (a) Proximity to road and trail; sight, sound, and distance from other sites, water, toilet facilities, etc. (b) Ecological setting such as elevation, exposure, vegetation type (micro and macro), and shading.

Shelterwood harvest and salvage logging provide recreational opportunities in a more natural setting. Natural barriers limit use and provide solitude and privacy. (Courtesy Mark L. Hopkins, personal photograph)

8. What sites are attracting most use and least use? What are the common characteristics of the overused and underused sites?[3/] This is important information for identifying potentially new sites and relocating old campsites. For example, if an old site is closed, a new, equally attractive site may need to be established. The environmental impact may be doubled if both the new site and the old one are used.

9. What changes occur at the sites over time? Another use of Code-A-Site data is for monitoring over time (as opposed to inventory) changes in environmental impacts from recreational use. The Code-A-Site system explained in this publication relies solely on field judgments of environmental impacts which may not be precise enough for detailed

[3/] For studies of dispersed campsite selection and use, see Merriam et al. (1973) and Merriam and Smith (1975).

assessment of environmental impacts. However, extra space has been provided on the card which could be used for recording more detailed measurements of site impacts.[4/]

One of the most important uses of Code-A-Site is for inventorying the number of campsites and their environmental impacts in Wilderness and back-country areas. This is basic planning information and can help determine the need for camping restrictions in areas where overuse is suspected.

10. How much dispersed use occurs? Code-A-Site data may be useful for approximating the amount of recreational use in a dispersed area. The number of impromptu sites established by campers reflects the amount of recreational use as does evidence of site use; e.g., environmental impacts, firewood, and litter. Although this kind of evidence is not an adequate measure of use, in the absence of a formal sample it may be the best measure available (James 1968). Although management of dispersed areas requires more information on the amount and kind of use, a Code-A-Site inventory allows managers to systematically aggregate subjective field judgments about the frequency of site use, thereby providing one estimate of the amount of dispersed use. In one study of three dispersed road recreational areas, field estimates of site use made during Code-A-Site inventories compared favorably with observations of total site use over one summer.[5/] But caution should be used in basing total use estimates on such data because the same study indicated that from 58 to 83 percent of the use at these dispersed road recreational areas consisted of day use, which may not be reflected in evidence at campsites.

[4/] In one case the National Park Service designed a special edge-punch card very similar to Code-A-Site for recording and aggregating quantitative information about human impacts at back country dispersed sites (Bruce B. Morehead, 1975, "Management Studies of Human Impact," summary of 1974 progress, 9 p., mimeogr.; available from author at Olympic National Park, Port Angeles, Wash. 98362). The Park Service study collected much more detailed information than called for in this Code-A-Site inventory system as their purpose was to study human impact phenomena.

[5/] Hendee, John C., Mack L. Hogans, and Russell W. Koch. Dispersed recreation on three forest road systems in Washington and Oregon: first year data. In preparation for publication, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

11. Where are sites located? Code-A-Site data can be plotted on maps to visually display any concentrations of sites, whose land they are located on, and the general pattern of site establishment. (This information can be useful in determining management responsibilities, possibly in share cost negotiations, planning fire patrol routes to maximize campsite contacts, and general land use planning.)

Code-A-Site information about the location, characteristics, impacts, and use of dispersed recreational sites is useful for planning and managing dispersed use and its coordination with other resources; e.g., fire patrol, fish stocking, road maintenance, timber harvest, wildlife management. (Courtesy Mack L. Hogans, personal photograph)

Applying Code-A-Site

Code-A-Site uses edge-punch cards and needle-sorting techniques to systematize the recording and handling of inventory data where use of computers is not feasible or desired. These are well-established techniques for data storage and retrieval.[6/] They have proved useful for easy but systematic handling of large numbers of public inputs in the recently developed CODINVOLVE system (Clark et al. 1974). The use of edge-punch card, needle-sorting technology is less complex, requires less training and equipment, and is more flexible than computers. These attributes could facilitate use of Code-A-Site information in resource analysis, planning, and management at local field levels. And, as previously indicated, where large volumes of data must be handled or the information is needed for other purposes, application of computer techniques is easily accomplished.

[6/] For basic information on edge-punch card technology, see Automated Business Systems (1969).

NATURE OF THE JOB

A Code-A-Site inventory consists of two types of jobs--fieldwork and office work. But before beginning data collection, the data user (manager) must decide what kind of information is needed and how much. Thus, with clear objectives in mind, he may review specific items in the Code-A-Site coding instructions (part 2 of this paper). In this manner, additions or deletions in the coding categories can be made to provide the most efficient use of money and manpower in gathering data. The key is to make the system fit local conditions and needs--only information that will be used should be collected. Flexibility has been built into the system by providing extra space on the Code-A-Site card so that it can be used without modification if a manager wants to gather additional, special information.

Generally, except for the addition of extensive data for a specific study, the basic Code-A-Site card has sufficient flexibility. Use of the basic, preprinted Code-A-Site cards will result in substantially lower card costs and greater comparability of inventory data between management units. The January 1976 cost of Code-A-Site cards ranged from 31 cents each for an order of 1,000 cards to 7 cents each for 50,000 cards. In a 1975 consolidated order for 20,000 cards, Region 6 of the U.S. Forest Service paid about 10 cents per card.

Fieldwork.--Personnel who routinely travel through the areas to be inventoried are often able to fit campsite inventory into their other duties. This approach has been successfully used in several pilot study areas and works well if the inventory job is spread over a sufficient time period. In other cases, someone might be specifically assigned to complete the entire job more quickly than may be possible by persons with other responsibilities.

Field personnel who routinely travel forest roads can inventory dispersed sites with the Code-A-Site system as they perform other duties. (Courtesy Mack L. Hogans, personal photograph)

Inventorying an individual site with Code-A-Site usually takes only 10 to 20 minutes. (Courtesy Mack L. Hogans, personal photograph)

The fieldwork entails locating each site, plotting it on a base map, and entering desired information on the Code-A-Site card while at the site. In-the-field coding can usually be completed in less than 10 minutes per site after a person learns the system. Onsite time can be minimized if only the necessary information is completed in the field and the rest done in the office.

Office work.--Coding can be completed in the office. This includes adding code numbers for locating the site, writing a general description of the site, adding any management notes, preparing the cards for punching, and punching them. After the necessary office work has been completed, cards and base map should be stored for easy retrieval of information about all sites or any particular site.

BASIC STEPS IN A CODE-A-SITE INVENTORY

For a Code-A-Site inventory, experience suggests the following procedure:

1. Identify sites. On forest roads, this can be done by systematically driving on the roads and adjoining spurs and assigning, on a map, a tentative code number to all sites located. Usually sites can be identified by the presence of a fire circle. Sometimes a busy weekend is the best time to locate sites as some may be missed unless campers are there. For example, in one case, an initial midweek attempt to identify sites by an experienced local person revealed 40 sites in one area. Followup during peak weekend use revealed a total of 120 sites.

In roadless areas, known sites can be approximately located on a map. Back country or wilderness patrolmen can then systematically cover the vicinities where there are known concentrations of sites and can code other sites discovered during their travel. Location of sites should not be an office job. Our experience indicates serious mistakes and inaccuracies can result unless a systematic procedure is employed on the ground; generally, there are more sites than were expected.

2. Collect field data on Code-A-Site cards. Responsible personnel should visit each site to make necessary judgments for coding all desired data for each site on a separate edge-punch card following codebook instructions (part 2 of this report). Experience shows that familiarity in field data collection will reduce the time required to less than 10 minutes per site. Initial attempts will take longer until the field person memorizes the coding instructions.

3. Complete and punch cards in the office. Some site data, such as legal description and road number, can be completed in the office. When all desired data have been entered, the edge of the cards must be punched where they have been coded so it will be possible to sort them. A special punch for this can be purchased. About 1 minute per card is needed to punch holes for all possible data that might be collected.

4. Analyze data. When the manager has decided what data summaries are desired, they can be compiled by needle-sorting procedures. For example, he might want to identify all sites with "extreme" physical impacts from use, sites requiring work or maintenance, or a list of sites with space for four or more vehicles. An infinite number of summaries is possible but we have found managers most interested in the basic issues and questions listed earlier.

Code-A-Site inventorying of data about dispersed sites can be plotted on maps or summarized in reports as an aid to land use planning, decisionmaking, or work scheduling. (Courtesy Mack L. Hogans, personal photograph)

SOURCES OF INVENTORY DATA

Many types of data can be stored on the Code-A-Site card. Sources of this information may include: manager observations and ideas for the site, personal experiences in the area, and information from contacts with users. Thus, Code-A-Site provides for objective and subjective

assessments of site characteristics, use, and management and user needs. In addition, information about any one site can be compiled over an extended period of time which will allow for an assessment of change in the condition or use of the site.

Onsite observation.--Most of the data on the card can be derived by onsite inspection and observations; e.g., site description, location, facilities, and impact. Also, watching users can help the person inventorying make better judgments for items such as the principal activity on the site and frequency of use.

Personal experience.--Items such as frequency of use can best be determined by observation of the site over time. However, personnel who work or recreate in an area are often able to judge frequency of use in lieu of more complete data or can provide other useful data.

Users.--Asking users about frequency of use, activity on the site, etc., during routine visitor contacts is another source of information. Users often have many years of experience in the area and can provide information useful to the manager.

LEVEL OF MEASUREMENT

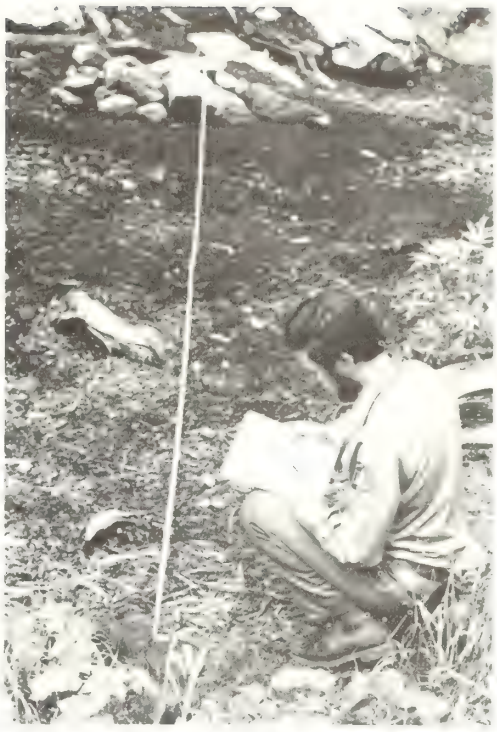
In many cases, there may be technical information underlying the subjective field judgments coded into the system; e.g., extent of environmental impact. One might be disturbed about whether or not such judgments can be made with sufficient accuracy and reliability. We are operating under the assumption that such judgments are made every day by managers. Our objective is to systematize the handling of these subjective field judgments and other more easily measured site attributes, by bringing together in the coding instructions criteria upon which such judgments can be based. The guidelines set forth in the codebook have been subjected to expert technical review and have been field tested. Code-A-Site is a system for handling state-of-the-art field judgments; additional basic research and development are obviously needed to develop better criteria for judging such things as environmental impacts and experience levels.

There is an extensive literature about ecological and recreational topics that might pertain to recreational sites. Many of these have been summarized in bibliographies by Stankey and Lime (1973) and James (1972). The coding criteria used in Code-A-Site should not be regarded as a substitute for basic information reported in the literature. On the other hand, the application of a system such as Code-A-Site may surface technical deficiencies in subjective field judgments and thus help focus needed research on them.

Field Test Areas

Code-A-Site was field tested during 1974 and 1975 at several locations including the following for which illustrative data summaries are included. A complete printout of Code-A-Site data for the Greenwater, Taneum-Manastash and Upper Clackamas dispersed road recreation areas is included in Hendee et al. (see footnote 5, p. 7).

Code-A-Site provides for field judgments of environmental impacts and more detailed measurements of impacts if desired. Data from detailed measurements can be useful in monitoring and assessing the aggregate impact of recreational use over time. Here, a Glacier Peak Wilderness patrolman on the Darrington District, Mount Baker-Snoqualmie National Forest, takes transect measurements of the impacted campsite area.



FOREST ROADS

Mount Baker-Snoqualmie National Forest in Washington--White River Ranger District.--1. *Greenwater Drainage:* A heavily clearcut drainage with active logging, about 1 hour from Seattle, Washington. It adjoins Highway 410, a major route to Mount Rainier National Park and eastern Washington via Yakima. The area includes 68 miles (109.4 kilometers) of logging roads and spurs, some private land, and a joint share-cost maintenance of some roads with cooperating landowners. The Greenwater is a focal point for motorbike use, berrypicking, camping, hunting, and general recreation.

2. *Huckleberry Creek*: A side drainage of the White River with approximately 36 miles (57.9 kilometers) of timber sale roads and active logging. Like the Greenwater, it lies about 1 hour from Seattle, adjoining Highway 410. The drainage features a trail to Mount Rainier National Park from the road end, Sun Top Lookout, a nonglacial stream, and dense Douglas-fir forest interspersed with clearcuts.

Mount Baker-Snoqualmie National Forest--North Bend Ranger District--1. *Middle Fork of Snoqualmie River*: North of Interstate 90, the main route between Seattle and eastern Washington State, the Middle Fork lies 1 hour from Seattle and contains 30 miles (48.3 kilometers) of timber sale roads plus some spurs. Much of the lower drainage was logged off years ago, but the upper reaches beyond the road's end lead to spectacular roadless high country in the proposed Alpine Lakes Wilderness. The drainage has much day use, three major trail heads,

a portable guard station, and one 24-unit campground. Camping, hiking, and mountain climbing in the adjacent roadless areas are popular, as is fishing in the river.

2. *North Fork of Snoqualmie River*: Located farther north on Interstate 90, 18 miles (29 kilometers) from the town of North Bend, Washington. This drainage terminates in the proposed Alpine Lakes Wilderness beyond the road's end. The drainage includes 15 miles (24 kilometers) of road on National Forest land and, like the Middle Fork, features hiking, climbing, fishing, camping, and two major trail heads.[7/]

ROADLESS AREAS

Deschutes National Forest, Oregon--Bend Ranger District.--The Green Lakes vicinity of the Three Sisters Wilderness, one of the most heavily used locations in classified Wilderness in the Pacific Northwest. The area inventoried included 10 miles (16.9 kilometers) of trail.[8/]

Wenatchee National Forest, Washington--Naches Ranger District.--A 27-mile (43-kilometer) stretch of the Pacific Crest Trail on both north and south sides of Chinook Pass (Highway 410) from junction 2000/951 (Cougar Valley Trail) to Fish Lake. The southern portion lies in the proposed Cougar Lakes Wilderness study area.[9/]

Table 1 is a sample summary of data collected in the summer of 1974 with the Code-A-Site inventory system.

[7/] A more detailed report is contained in Mack L. Hogans, "Public Use of Forest Roads Pilot Study, Summer 1974, Mount Baker-Snoqualmie National Forest: White River and North Bend Ranger Districts," unpublished 1974 report available from the author, 4507 University Way N.E., Seattle, Wash. 98105.

[8/] Detailed information is included in Dan Wood, "Public Use of Forest Roads Pilot Study--Deschutes National Forest, Bend and Sisters Ranger Districts," unpublished 1974 report available from author, 4507 University Way N.E., Seattle, Wash. 98105.

[9/] Detailed information is included in Russ Koch and John Hendee, "Code-A-Site Inventory of Dispersed Sites on Pacific Crest Trail--Naches Ranger District," unpublished 1975 report available from authors, 4507 University Way N.E., Seattle, Wash. 98105.

Table 1--*Summarized data about dispersed sites collected in the summer of 1974 with Code-A-Site*[1/]

Road or trail	Miles	Number of sites inventoried	Density (sites per mile)	Site origin		Extreme or heavy environmental impact[4/]	Maximum number of spaces available at sites	Estimated 1-night capacity, PAOT[5/]
				Official[2/]	Impromptu[3/]			
				- - Number of sites - -				
Road:								
Greenwater drainage	68	128	1.9	1	127	50	392	1,568
Huckleberry Creek	36	40	1.1	1	39	10	135	540
North Fork, Snoqualmie River	15	35	2.3	0	35	4	66	264
Middle Fork, Snoqualmie River	30	75	2.5	1	74	12	255	1,020
Total or average	149	278	1.9	3	275	76	848	3,392
Trail:								
Green Lakes	10	80	8.0	0	80	32	177	708
Pacific Crest	27	79	2.9	10	69	17	79	315
Total or average	37	159	4.3	10	149	49	256	1,023

[1/] In addition to the data shown here, the inventory yielded a map with location of each site plotted and extensive information on site resources such as water, firewood, available activities, attractions, site descriptions, and notations about needed work or problems at the site.

[2/] Established by agency.

[3/] Established by campers.

[4/] See the Code-A-Site codebook for criteria used to judge categories of environmental impact.

[5/] People at one time--assumes 4 persons per party and all tent and vehicle spaces at each site occupied. The capacity would be much less under 1-party-per-site assumption.

PART 2. CODEBOOK--INSTRUCTIONS FOR APPLYING CODE-A-SITE

Introduction

This codebook is a guide for entering recreational site information on the edge-punch cards. Each category found on the card is explained. Categories begin in the upper left corner on the front of the card and proceed counterclockwise around the edges.

When sites are coded, any notations for a particular coding category may be made in the space provided in the center of the card. Such notations should be clearly marked as to which category they pertain; if a notation pertains to more than one category, each category should be identified.

Specific methods and adaptations of Code-A-Site to local situations depend on local managers. The following suggestions come from our own 2 years of field testing and the experience of several managers who have applied Code-A-Site.

CODING TIPS

The key to useful coding of any data is a clear idea of its use. The entire card need not be completed if all the information is not useful or desired. Local managers should decide what data they want or need and restrict data collection to those items. Managers should feel free to redefine coding rules to better serve their needs. It is important, however, that all coders in any particular area use the same rules and that a record of the coding rules be kept so the data can be interpreted correctly by future users.

The Code-A-Site edge-punch cards have additional writing space and a special section that can be used for recording whatever information managers think is important--whether or not it is called for in coding instructions.

Expanding the site numbering system can be useful for quickly locating a site on a map or in the field. Letter codes such as "N" or "S" for north or south can be added to a site's regular number without disrupting the system. For example, number "15S" means site number 15 on the south side of the road or trail. This is especially helpful in congested areas.

Color coding is also a good method for quick sorting and organizing of the inventory cards. A combination of blue, red, green, etc., slashes across the tops of all cards could facilitate sorting.

USE OF MAPS

Maps can be useful for displaying inventoried sites and for summarizing information. When sites are clustered, a map with a large enough scale to distinguish between individual sites is necessary. In heavily used dispersed areas, a 4-inch-scale map may be necessary, but in remote

areas a 1-inch-scale may provide sufficient space to indicate site locations.

When precise topographic location of a campsite is desired, a large-scale contour map is needed.

How the maps will be used must also be considered; e.g., semipermanent office maps or portable maps for field use by patrolmen. Sometimes two maps may be needed for different purposes.

USE OF PHOTOGRAPHS

In some cases, photographs of the sites may be desired to aid in describing the site or for giving information to users on the types of sites in an area. Photos can also be useful when impact and use over time are appraised.

Using the System

The following instructions indicate the location and type of information to be included on the Code-A-Site cards. Figures 1 and 2 show the front and back of the card before any information has been entered; figures 3 and 4 show a coded and punched card. Code-A-Site users should refer to these figures for examples of how the card is used.

Instructions for Coding the Front of the Code-A-Site Card

I. DESCRIPTIVE INFORMATION (1 through 10)

1. Type of area. Check the general category of the area in which the site is located.

   a. Dispersed roaded.
   b. Back country or roadless area.
   c. Wilderness (legal).
   d. Other (specify).

2. Access. Check whether the site is accessible all year round or seasonal only. If access is seasonal, specify when and why; e.g., "from mid-June to the end of Sept., snow during winter."

Check kind of access to the site:

3. Roads. *Main road*--paved or gravel main line logging road (designate road surface).

   Spur road--secondary road off a main line, easily passable by passenger car when dry.

   Informal (car) road--primitive road but still normally passable by 2-wheel drive vehicle; e.g., some abandoned skid roads.

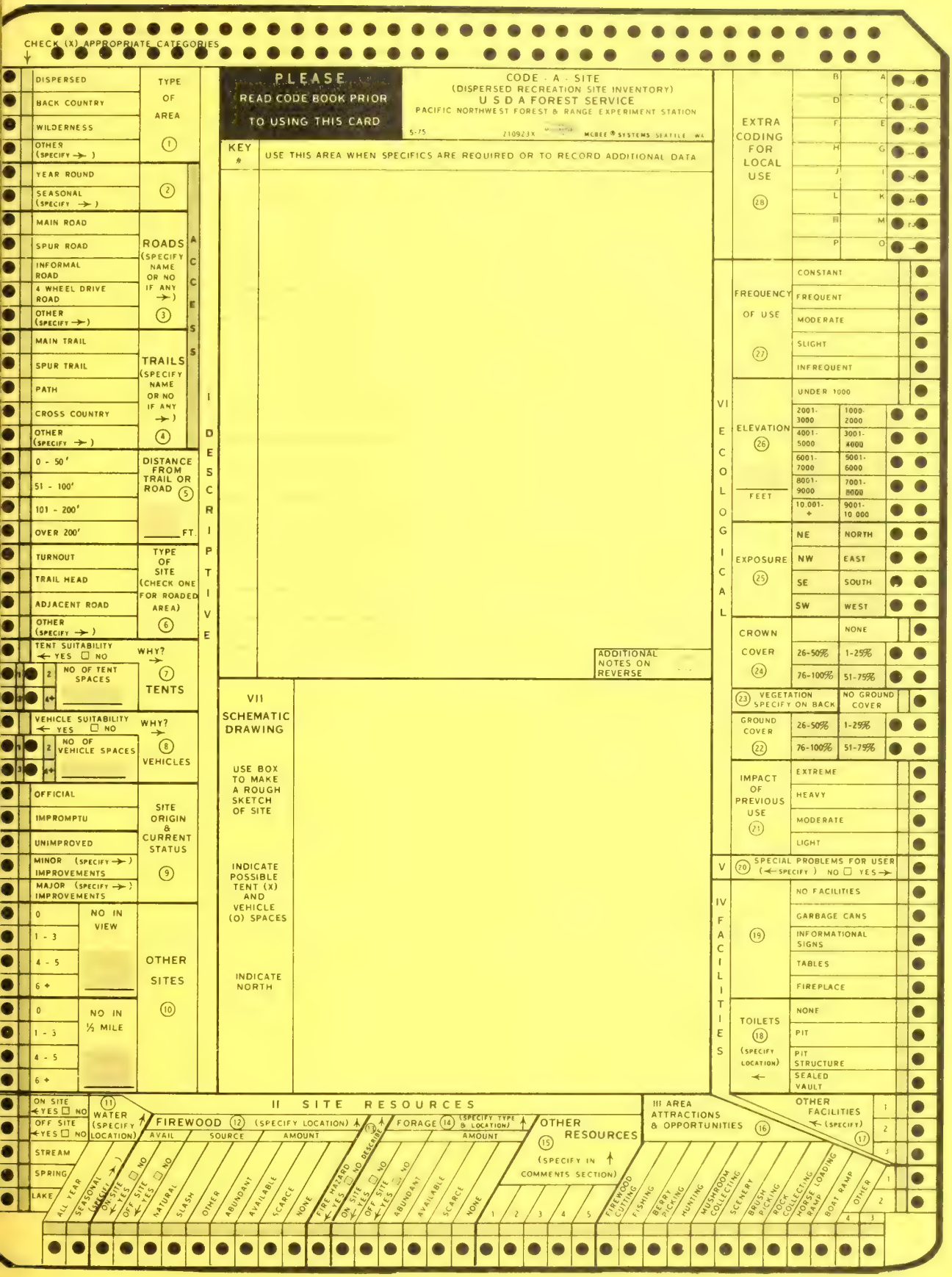


Figure 1.--Front of a Code-A-Site inventory card.

	TENS		UNITS		TENS		UNITS		TENS		UNITS		1 2 0'S	HUNDREDS	TENS	UNITS
	2 1	0	7 4 2 1		2 1	0	7 4 2 1		2 1	0	7 4 2 1			7 4 2 1	7 4 2 1	7 4 2 1
X	FOREST CODE				DISTRICT CODE				MGMT. UNIT				SITE NUMBER			

REGION _____ FOREST _____ DISTRICT _____

TOWNSHIP _____ RANGE _____ SECTION _____ DOT ⊹ MGMT UNIT _____ SITE NO _____

DATE CODED _____ CODED BY _____

GENERAL DESCRIPTION OF SITE	
MANAGEMENT NOTES	
FUTURE MANAGEMENT RECOMMENDATIONS AND SITE COSTS	

KEY #	USE THIS AREA WHEN SPECIFICS ARE REQUIRED OR TO RECORD ADDITIONAL DATA
(23)	ON SITE VEGETATION
(23)	OFF SITE VEGETATION

Figure 2.--Back of a Code-A-Site inventory card.

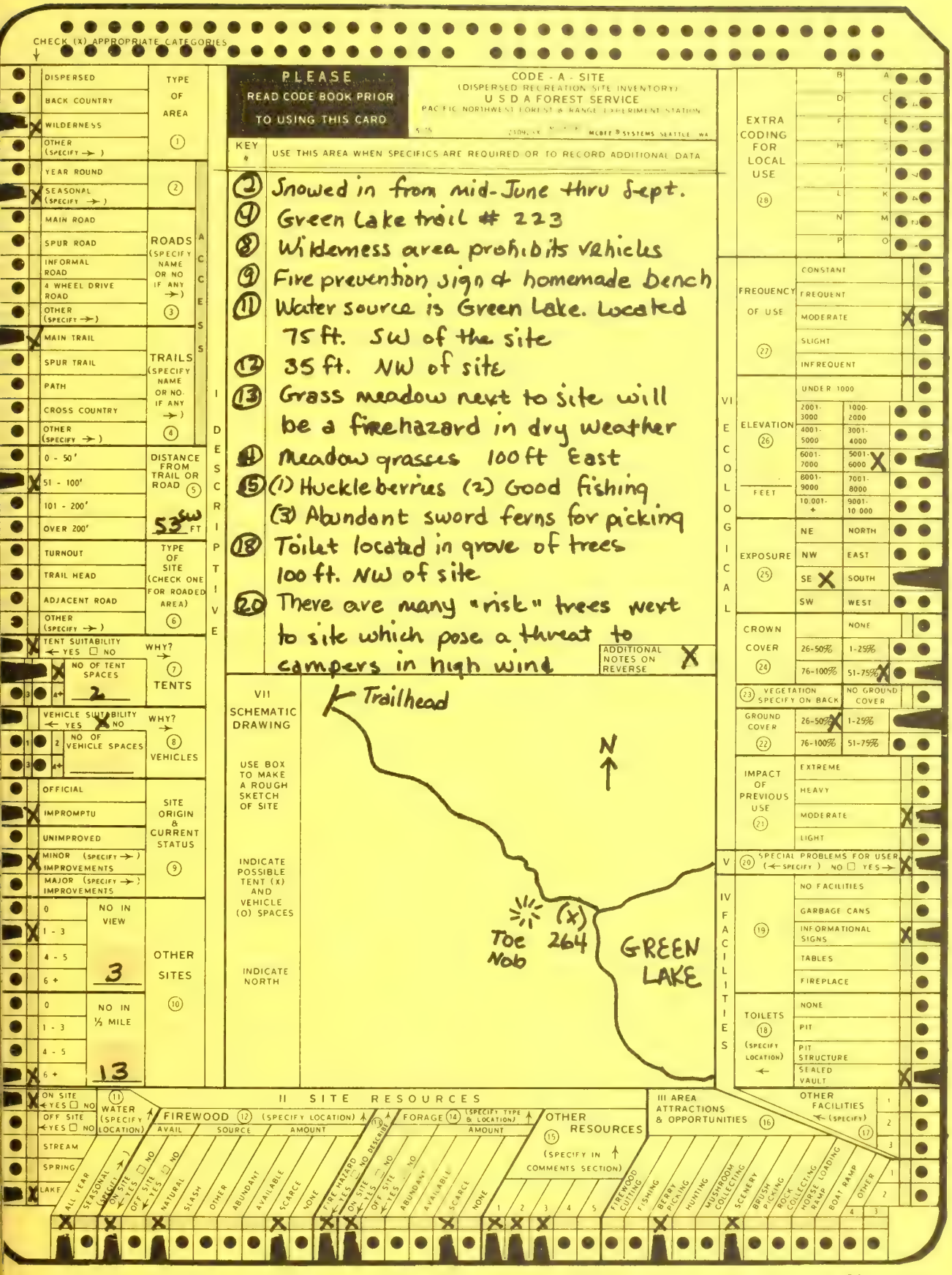


Figure 3.--Front of a coded and punched Code-A-Site card.

X	FOREST CODE	DISTRICT CODE	MGMT. UNIT	SITE NUMBER
	TENS 2 1 0 / UNITS 7 4 2 1	TENS 2 1 0 / UNITS 7 4 2 1	TENS 2 1 0 / UNITS 7 4 2 1	1 2 0'S HUNDREDS 7 4 2 1 / TENS 7 4 2 1 / UNITS 7 4 2 1

REGION 6 FOREST Deschutes DISTRICT Bend - 18

TOWNSHIP 17S RANGE 8E SECTION 4 DOT MGMT UNIT Green Lake #10 SITE NO 264

DATE CODED 8/29/74 CODED BY Jim Smith

GENERAL DESCRIPTION OF SITE

Site is a 2 tent-space area utilizing a common rock fire ring. Site is adjacent to Green Lake in a sparse stand of true fir. There are other sites in the general area. Has outstanding view.

MANAGEMENT NOTES

FUTURE MANAGEMENT RECOMMENDATIONS AND SITE COSTS

1 sealed vault. Price: $ 150
1 fire prevention sign. : 35
185

KEY # — USE THIS AREA WHEN SPECIFICS ARE REQUIRED OR TO RECORD ADDITIONAL DATA

(23) ON SITE VEGETATION Site is located in sparse stands of true firs and scattered D. firs and lodgepole pine - Ground cover is lupine and pine grass and meadow grass

(23) OFF SITE VEGETATION Douglas-fir is major timber type - Ground cover consists of salal devil's club. Some scattered Western Red cedar also.

Figure 4.--Back of a coded and punched Code-A-Site card.

4-wheel drive road--primitive road, passable only by 4-wheel drive vehicle.

Other--(specify).

4. Trails. *Main trail*--main line trails which normally are assigned identifying names and numbers and receive regular maintenance.

Spur trail--secondary trail connecting a main trail to some attraction such as a nearby lake. Trail is normally shown on maps and is maintained.

Path--informal trail established by use rather than planned construction. Trail is likely not to be on maps and is not normally maintained.

Cross country--no existing trail; maybe a general travel route less defined than even a "path."

Other--(specify).

NOTE: Nomenclature for trails and roads can easily be adapted to the local area. The terminology used here describes access from a user perspective--i.e., from easy to difficult access--local managers may want to use other terms such as primary, secondary, tertiary, or long term, short term. The changes can be made by noting: "our main road = your primary road" or "our main trail = your trunk trail." The printed card can usually be used without modification, or appropriate terminology can be written in.

5. Distance from trail or road. Check the appropriate box. Specify distance and direction from trail to center of site in the shaded box provided; e.g., 53 ft. SW. Use the space provided in the middle of the card if needed for additional comments.

6. Type (location) of site (for roaded areas only). Check the category which most closely describes the type of site. If the "Other" category is chosen, describe the site in the space provided in the middle of the card.

   a. *Turnout site*--sites in wide area of the road, used by cars to stop for recreational purposes--parking, camping, viewing scenery, etc.

   b. *Trail head site*--sites at parking area for access to a trail system.

   c. *Adjacent road site*--sites adjacent to road but not in one of the above categories; e.g., campsite 50 feet off road on informal spur.

   d. *Other*--any site which does not fit into the above categories. Use the space for details.

7. Tents. *Suitability*--check yes or no to indicate if the site is suitable for tents. Use the space provided to explain why or why not.

   Number--check the number of tent spaces available. If more than four, write the number in the shaded box.

8. Vehicles. *Suitability*--check yes or no on the card to indicate if the site is suitable for recreational vehicles. Use the space for explanation.

   Number--check the number of vehicle spaces available. If more than four, give maximum number.

NOTE: Available spaces can best be determined by visiting the site during periods of heavy use.

9. Site origin & current status. Check the appropriate box.

   a. *Origin* (check one):

      (1) Official--planned, designed, and constructed by the managing agency.

      (2) Impromptu--sites established by campers.

   b. *Current status* (check one):

      (1) Unimproved--no improvements or facilities provided.

      (2) Minor improvements (specify)--some minor improvements. Site usually not shown on maps.

      (3) Major improvements (specify)--major improvements such as signs, tables, fireplaces, etc. Site usually shown on maps. (Some dispersed sites gradually grow into official sites as facilities are added.)

10. Other sites:

   a. *Number of sites within view*--check the category which indicates the number of sites within view from the site being inventoried. If more than six are within view, specify the maximum number in the shaded box. (This number may change as use increases in the area and new sites are established.)

   b. *Number of sites within one-half mile*--(can be filled out in the office from a map). Check the box which indicates the number of sites within one-half mile from the site being inventoried. Specify the exact number in the shaded box. (This number may change as use increases in the area and new sites are established.)

II. SITE RESOURCES (11 through 15)

This section is for appraising the resources of the area available for campers' use. (As these resources may change over time, it will be necessary to review their availability in the future.)

Definitions: 1. Onsite--within 200 feet from edge of site.
2. Offsite--over 200 feet from edge of site.

11. Water: *Availability*--onsite--check yes or no;
offsite--check yes or no.

Location--use the center of the card to specify distance and direction of water source from the campsite.

Source--check all choices that apply as a source of water to the site: (a) lake, (b) stream, (c) spring.

Continuity--check whether the water source is year-round or seasonal. If seasonal, specify when it is available.

12. Firewood: *Availability*--onsite--check yes or no;
offsite--check yes or no.

Location--use the center of the card to specify direction and distance of firewood from the campsite.

Source--check that which most closely describes the firewood source:

a. Natural debris--dead limbs and down trees which normally occur near the site.
b. Slash--debris left by logging or other man-caused activity.
c. Other--any other source such as "old burn" or "bug kill patch" (specify).

Amount--check the category which most closely describes the amount of firewood:

a. Abundant--large concentration of firewood; several years' supply even with heavy use; e.g., result of storm damage, windthrow, logging.
b. Available--firewood plentiful but could be depleted through heavy use over a few years.
c. Scarce--firewood will soon be exhausted.
d. None--only live vegetation, esthetic snags, or nothing available.

13. Fire hazard: Check yes or no. Comments describing the hazard may be placed in the middle of the card. For example, "during periods of extremely dry weather, grass meadow next to the site will be an extreme fire hazard."

14. Forage: *Availability*--onsite--check yes or no;
offsite--check yes or no.

Type--describe the type of forage; e.g., thinly spaced clumps of pine grass throughout the area.

Location--direction and distance from site; e.g., large meadow one-half mile south.

Amount--check the category which most closely describes the amount of forage:

a. Abundant--abundant forage for recreational livestock; can absorb frequent grazing without depletion or damage.
b. Available--forage exists but could be depleted with frequent use.
c. Scarce--little forage exists for livestock grazing--a few animal-days supply only.
d. None--no forage that will sustain grazing.

15. Other resources: Five possible punches are provided for this category. They may be used in a variety of ways. For example, number 1 could simply mean "yes there are other resources," and explanations could be made in the space provided in the center of the card. Another method could be to use numbers 1 through 5 to correspond to specific resources; for example, 1 = huckleberries, 2 = good fishing, 3 = abundant ferns for picking, etc.

III. AREA ATTRACTIONS & OPPORTUNITIES

16. Check opportunities or attractions that apply and list any not specifically listed on the card. Use "Other" category for activity opportunities and facilities that may be unique to your area; list these in the blank in the middle of the card. You may want to ask users why they come to a particular site.

Examples:

a. Firewood cutting.
b. Fishing.
c. Berry picking.
d. Hunting.
e. Mushroom collecting.
f. Scenery.
g. Brush picking.
h. Rock collecting.
i. Horse loading ramp.
j. Boat ramp.
k. Other.

IV. FACILITIES (17 through 19)

These spaces are to indicate facilities, both official facilities and those established by campers, that are available at the sites.

17. Other facilities: Specify facilities not listed in 18 and 19.

18. Toilets (check applicable boxes):

a. *None*--no toilet facilities.
b. *Pit*--an open pit toilet, possibly a latrine, near a site. Include open Wallowa-type box toilets.
c. *Pit structure*--pit toilet but with enclosed outhouse.
d. *Sealed vault*--a sealed vault or chemical toilet.

Location--specify the distance and direction of toilet from site.

19. Specify number and kind of facilities available:

a. No facilities.
b. Garbage cans.
c. Information signs.
d. Tables.
e. Fireplaces.

V. 20. SPECIAL PROBLEMS FOR USER: Check yes or no for special problems; e.g., mosquitoes, hazardous trees, etc. Clearly specify the hazard in the space in the middle of the card. For example, "this site is located in a very old stand of Douglas-fir trees. Many are 'risk' trees and pose a threat to campers, especially in windstorms."

VI. ECOLOGICAL INFORMATION (21 through 28)

21. Impact of previous use. This category calls for subjective field judgments of use impacts. The information will help to appraise environmental impact, rehabilitation potential, and carrying capacity of the site. Relative impact of use is based on specific indicators. Use these indicators to appraise and describe the site's condition:

To what extent is ground vegetation impacted or the site denuded? Are there any exposed roots, dead trees, or visitor use trails radiating from the site? Is there any erosion?

Use-impact categories. Using the above indicators, make an overall judgment about the physical impact at the site. (Check appropriate choice on the card.)

a. *Extreme impact*--all previous ground vegetation gone; many roots exposed. Erosion beginning--further deterioration will continue even without use. Impact of site has spread to surrounding area. Soil is compacted and restricts new vegetation.

b. *Heavy impact*--substantial impact but no continuing deterioration without use. Site would rehabilitate if not used. Most ground vegetation gone. Some roots exposed. Visual impact generally restricted to the site area. Visible trails radiate from the site. No permanent erosion.

c. *Moderate impact*--some denuded spots in the ground cover but vegetation is relatively intact. No exposed roots and impact is limited to the immediate site.

d. *Light impact*--ground vegetation completely intact. Natural processes at the site may be somewhat retarded by use.

22. Ground cover: Check percentages most closely representing amount of ground cover at the site.

23. Vegetation: Indicate at this location if there is no ground cover. If ground cover is present, specify its nature on the back of the card:

Onsite (use back of card to record notes--figure 2, p. 20)--vegetation in the immediate area. A description of the major timber type and ground cover; e.g., "site located in a clearcut, regeneration is 15-year-old Douglas-fir averaging 10 feet. Ground cover consists of some salal in spots and some Oregon grape." Or "Site located in relatively pure subalpine fir stand, mixed age. Ground cover is sparse, but some lupine and pine grass may be found." There is no substitute for specific, measured ecological data, but the description should be sufficient to identify the plant communities involved. Information on the stand could include age, height, d.b.h., age distribution, and other information the manager may find useful.

Offsite (use back of card to record notes--figure 2, p. 20)--vegetation in the surrounding area. The objective is to provide enough descriptive information to correspond to standard vegetation classification such as vegetation zones and physiographic provinces as outlined in Franklin and Dyrness (1973). Describe major timber type and dominant ground cover; e.g., "coastal Douglas-fir is the major timber type with ground cover varying from devil's club to salal." Or "Mixed stands of larch and true firs with sparse ground cover due to rocky slope, but some lupine and other wildflowers where soil is present."

24. Crown cover: Check percentages most closely representing amount of crown cover at the site.

25. Exposure: Aspect to which the site is generally exposed; e.g., "site slopes toward the south" or "site exposed to the northeast."

26. Elevation: In feet to the nearest hundred (can be taken from topographic maps). Specify exact elevation in shaded portion of card.

27. Frequency of use (see figs. 1 and 3): Appraise how often the site is used by inspecting ecological impact and other evidence: fire ring, ashes, and debris; annual vegetation growth; litter; latrine; other signs of use; contacts with users of the site. Observations by patrolmen over the use season may provide the best judgment of use. If use varies by season, describe the nature of variation; e.g., infrequent use in summer but constant use during hunting season.

Use categories:

a. *Constant*--always used on weekends during the season and frequently during the week.

b. *Frequent*--used much of the time, almost always during heavy use periods such as "most weekends."

c. *Moderate*--used about half the time during the season.

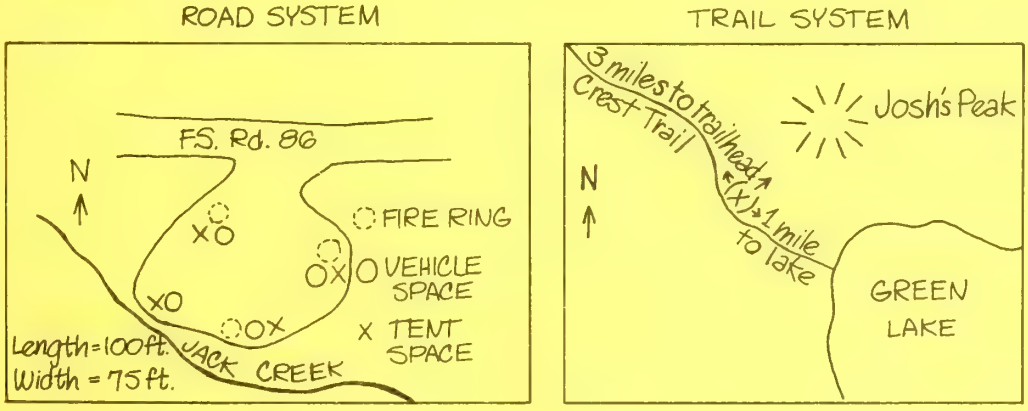
d. *Slight*--used only a few times a season such as during heavy use periods.

e. *Infrequent*--use is light; site may be used only once a year or not at all.

28. Extra coding for local use: This section of the card is reserved for additional data not prescribed for in Code-A-Site instructions, but which local managers might wish to collect. There are no criteria on how to use this space. It may be useful for recording more detailed information about the site in any category. The instructions for using this section must be developed by local managers.10/

VII. SCHEMATIC DRAWING (bottom center of card): Use this portion of the card for a schematic drawing of the site. This will add greatly to the site description. Also indicate on this map the possible location of tent (X) and vehicle (O) spaces. Specify dimensions of the site and its location with respect to roads, trails, and bodies of water.

Example:



10/ See footnote 4, p. 7, for reference to manuals providing basic instructions for recording data on edge-punch cards.

Instructions for Coding the Back of the Code-A-Site Card

The following information is to be included on the back of the card. Refer to figures 2 and 4 for an example of coding this information. Most items on the back of the card may be completed in the office.

Locational data: Directly under the holes at the top of the card, additional space for writing locational and other information is provided. The names (or number) of the Region, Forest, District, or management unit may be written in this space. These particular designations conform with the U.S. Forest Service nomenclature. They may be easily changed to conform with other agency nomenclature by writing in the appropriate designations.

Region: The administrative Region in which the site is located. Use standard agency code numbers.

Forest: The name of the National Forest, Park, or other management unit in which the site is located. Use standard agency code numbers.

District: The name of the Ranger District or local administrative unit in which the site is located. Use standard agency code numbers.

Management unit: This is simply a "catchall" term for the many ways Districts or local administrative units may be zoned or divided to facilitate local management. These are often Fire Management or Timber Management areas but could be any other division the administrator feels is appropriate. The management units often have names (e.g., "Buck Creek Fire Patrol") and need only be assigned a code number to be punched at the top of the card.

Site number: Indicate the code sequence number which was assigned to the site.

Legal description: Indicate the township, range, and section in which the site is located. Place a dot in the box provided to illustrate where the site is located in the section.

Date coded: Indicate the date on which the site was coded or inventoried.

Coded by: Place the name or initials of the person inventorying the site.

GENERAL DESCRIPTION OF THE SITE: Describe the site as you would to a camper. For example, "Heavily used site at the north edge of Square Lake. Located on a windy hill but has a good view of the lake. Good screening from other campsites."

MANAGEMENT NOTES: Use this space for notations or observations about the management of the site. It can be used to record possible work needs which the manager would want to know about. For example, recent slash or windfall may pose a fire hazard in heavily used areas.

No specific criteria are available for judgments relating to management of the site; management objectives will determine these. Beware of the tendency to recommend facilities or improvements or other management actions. Rather, concentrate on describing the situation. Managers can decide later what should be done when information about all sites is available.

FUTURE MANAGEMENT RECOMMENDATIONS AND SITE COSTS: This space is reserved for the manager to indicate anything he thinks should be done to the site in the future. A record of total costs invested at the site for such facilities as picnic tables, garbage cans, signs, toilets, and for other work can be useful to the agency. See facilities, items 17, 18, and 19, on the front of the card.

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1975. Newly established campsites in the Boundary Waters Canoe Area. Restudy of selected sites - 1974. Minn. For. Res. Note No. 254, 4 p.

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GOVERNMENT PRINTING OFFICE 1976—796-234/ 9 REGION 10

Hendee, John C., Roger N. Clark, Mack L. Hogans, Dan Wood and Russell W. Koch.
1976. Code-A-Site: A system for inventory of dispersed recreational sites in roaded areas, back country, and wilderness. USDA For. Serv. Res. Pap. PNW-209, 33 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Code-A-Site is a system for inventorying dispersed recreation sites that are established by users along forest roads, in back country, or in wilderness. The system uses edge-punch cards and needle-sorting methods for recording, storing, and retrieving basic site information such as location, characteristics, available resources, activities, and impacts.

KEYWORDS: Recreation, recording methods (data), dispersed recreation, inventory, carrying capacity, wilderness, environmental impacts.

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The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

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Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

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Portland, Oregon 97208

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1976

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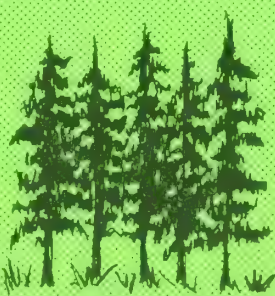
LEVELS-OF-GROWING-STOCK COOPERATIVE STUDY IN DOUGLAS-FIR

REPORT NO. 4 ROCKY BROOK, STAMPEDE CREEK, AND IRON CREEK



PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. Department of Agriculture
Forest Service
Portland, Oregon

Levels-of-growing-stock study treatment schedule, showing percent of gross basal area increment of control plot to be retained in growing stock

Thinning	Treatment							
	1	2	3	4	5	6	7	8
	Percent							
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

Abstract for Report No. 1

Public and private agencies are cooperating in a study of eight thinning regimes in young Douglas-fir stands. Regimes differ in the amount of basal area allowed to accrue in growing stock at each successive thinning. All regimes start with a common level-of-growing-stock which is established by a conditioning thinning.

Thinning interval is controlled by height growth of crop trees, and a single type of thinning is prescribed.

Nine study areas, each involving three completely random replications of each thinning regime and an unthinned control, have been established in western Oregon and Washington, U.S.A., and Vancouver Island, Canada. Site quality of these areas varies from I through IV.

Climatic and soil characteristics for each area and data for the stand after the conditioning thinning are described briefly.

KEYWORDS: Thinnings, stand growth, Douglas-fir, *Pseudotsuga menziesii*.

LEVELS-OF-GROWING-STOCK COOPERATIVE STUDY IN DOUGLAS-FIR

Report No. 4--Rocky Brook, Stampede Creek, and Iron Creek

by

Richard L. Williamson, Mensurationist

USDA Forest Service Research Paper PNW-210

Pacific Northwest Forest and Range Experiment Station
Forest Service
U.S. Department of Agriculture

Portland, Oregon
1976

Other LOGS (levels-of-growing-stock) reports:

WILLIAMSON, RICHARD L., and GEORGE R. STAEBLER.
1965. A cooperative level-of-growing-stock study in Douglas-fir. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., 12 p., illus. Portland, Oreg.

Describes purpose and scope of a cooperative study which is investigating the relative merits of eight different thinning regimes. Main features of six study areas installed since 1961 in young stands are also summarized.

WILLIAMSON, RICHARD L., and GEORGE R. STAEBLER.
1971. Levels-of-growing-stock cooperative study on Douglas-fir. Report No. 1--Description of study and existing study areas. USDA For. Serv. Res. Pap. PNW-111, 12 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Thinning regimes in young Douglas-fir stands are described. Some characteristics of individual study areas established by cooperating public and private agencies are discussed.

BELL, JOHN F., and ALAN B. BERG.
1972. Levels-of-growing-stock cooperative study on Douglas-fir. Report No. 2--The Hoskins study, 1963-1970. USDA For. Serv. Res. Pap. PNW-130, 19 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

A calibration thinning and the first treatment thinning in a 20-year-old Douglas-fir stand at Hoskins, Oregon, are described. Data tabulated for the first 7 years of management show that growth changes in the thinned stands were greater than anticipated.

Diggle, P. K.
1972. The levels-of-growing-stock cooperative study in Douglas-fir in British Columbia (Report No. 3, Cooperative L.O.G.S. Study Series). Can. For. Serv. Inf. Rep. BC-X-66, 46 p., illus. Pac. For. Res. Cent., Victoria, B.C.

Reference Abstract

Williamson, Richard L.
1976. Levels-of-growing-stock cooperative study in Douglas-fir. Report No. 4--Rocky Brook, Stampede Creek, and Iron Creek. USDA For. Serv. Res. Pap. PNW-210, 39 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The U.S. Forest Service maintains three of nine installations in a regional, cooperative study of influences of levels-of-growing-stock (LOGS) on stand growth. The effects of calibration thinnings are described for the three areas. Results of first treatment thinning are described for one area.

KEYWORDS: Thinnings, stand growth, Douglas-fir, *Pseudotsuga menziesii*.

RESEARCH SUMMARY

Research Paper PNW-210

1976

A regional, cooperative study of the influence of levels-of-growing-stock on stand growth was initiated in 1962. The U.S. Forest Service maintains three of the nine study areas: Rocky Brook--established in 1963, in a 27-year-old, site index 90 stand; Stampede Creek--established in 1968, in a 32-year-old, site index 120 stand; and Iron Creek--established in 1966, in a 19-year-old, site index 160 stand.[1/] This report describes the status of these study areas during the initial phases of the experiment.

In all three areas, growth in all thinned stands was considerably below that in unthinned stands. The two older stands responded similarly to the calibration thinning, with growth percent of thinned stands about 25 percent better than that of the unthinned stands. The youngest stand, Iron Creek, was so young that all trees were essentially free growing, so that little growth stimulation of individual trees due to thinning was possible. Here, growth has been proportional to growing stock.

The essentially free-growing condition of trees in thinned stands at Iron Creek continued into the first treatment period, as the control stands began to show signs of competition.

So far, smaller trees (codominants) in thinned stands seem to be growing more efficiently than larger trees. More time is needed to substantiate this difference.

[1/] Site indices have 100-year basis.

Introduction

HISTORY OF THE STUDY

Federal and State agencies and private industry are cooperating in a study of the influence of levels-of-growing-stock (LOGS) on stand growth. All cooperators follow a common study plan designed to examine (1) cumulative wood production, (2) tree size development, and (3) growth-growing stock ratios as affected by eight different thinning regimes. The cooperators, study plan, and individual study areas have been described earlier (Williamson and Staebler 1971). Separate reports about three of the study areas have also been published (Bell and Berg 1972, Diggle 1972).

This report describes growth during the calibration period for the three U.S. Forest Service study areas described in Report No. 1--Rocky Brook, Stampede Creek, and Iron Creek. Site quality at these three study areas ranges from mid-V at Rocky Brook through high-IV at Stampede Creek to mid-II at Iron Creek. Respective total ages at start of the calibration period were 27 (a correction of Report No. 1), 32, and 19 years. Only the calibration period has been completed in the Rocky Brook and Stampede Creek areas (Rocky Brook 1963-69, Stampede Creek 1968-73); the first treatment period has also been completed in the Iron Creek area (calibration period 1966-70, first treatment period 1971-73).

Methods

Details of experimental techniques and concepts are in appendix I, p. 9. One of the few instances where the study plan allows some discretion is in deciding whether to base the calibration thinning (reduction of growing stock to a common level among thinned plots at start of calibration period) on basal area or number of trees. At Rocky Brook, calibration thinning was based on preserving a common number of trees among plots; at the other two areas, it was based on preserving a common basal area among plots. The latter technique resulted in less variation in residual cubic volume among plots than did the former (tables 1, 2, 3, p. 11, 12, 13) when variation was expressed as a percentage of the mean volume.

Results and Discussion

Data on mortality and stand growth and development with respect to cubic volume, basal area, height, and quadratic mean diameter[2/] are presented below for the calibration period for all three areas. Growth in cubic volume, basal area, and quadratic mean diameter are then presented for the first treatment period for Iron Creek. Growth is also presented separately for "All Trees" and "Crop Trees" categories.

MORTALITY

The Rocky Brook area had the lowest site quality of the three areas and also the greatest density before the calibration thinning, as indicated by control plot densities. Moreover, residual volume at Rocky Brook averaged only 43 percent of volume before the calibration thinning compared with 61 percent at the other two areas (fig. 1, and table 4, p. 14). The drastic release at Rocky Brook probably increased environmental stress on residual trees. Trees in this area also sustained crown damage from a very deep, heavy snow which occurred soon (October to December) after the thinning. Mortality was generally heavier in thinned stands than in control stands (table 5, p. 15)--probably because the storm occurred so soon after the thinning. Seven plots were damaged so severely they had to be replaced. Mortality in some treatments averaged as high as 13 percent of the growing stock left after the thinning.

2/ Diameter of tree of average basal area.

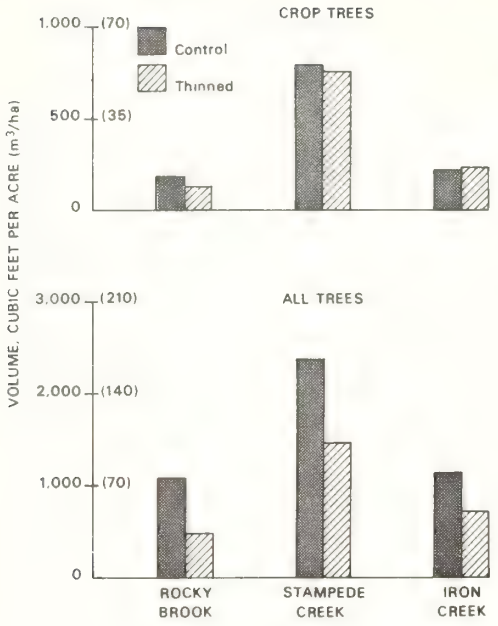


Figure 1.--Cubic volumes per acre after the calibration thinning, by study area.

Trees in the Stampede Creek area had no serious injury or mortality (table 6, p. 15). It differs from the other two areas mainly by being of natural origin and, consequently, having a greater range in individual tree ages and sizes.

The Iron Creek area had much mortality (table 7, p. 16) caused by the root pathogen *Armillaria mellea* Vahl. ex Fr. and by black bear. The root pathogen was apparently given impetus by a very severe drought during the 1967 growing season.

Black bear girdled many trees throughout this area before study establishment, and many of the trees left standing after the calibration thinning had been partially girdled. A bear went over a protective fence broken down by snow in spring 1972, girdled about 40 additional trees throughout the area, and killed 22 of these. These two kinds of damage have lowered site occupancy to an unknown degree on three plots.

GROWTH DURING CALIBRATION PERIOD

Cubic Volume

ALL TREES

The calibration thinning in all three areas was a heavy one by any standard. It is not surprising, therefore, that annual cubic volume[3/] growth of the thinned stands was considerably below that of the control stands during the calibration period (table 4, p. 14 , also fig. 2 and tables 8, 9, 10, p. 17 , 19 , 20). Metric equivalent tables follow tables 8, 9, and 10.

3/ All cubic volumes are based on volume equations described in Bruce and DeMars (1974).

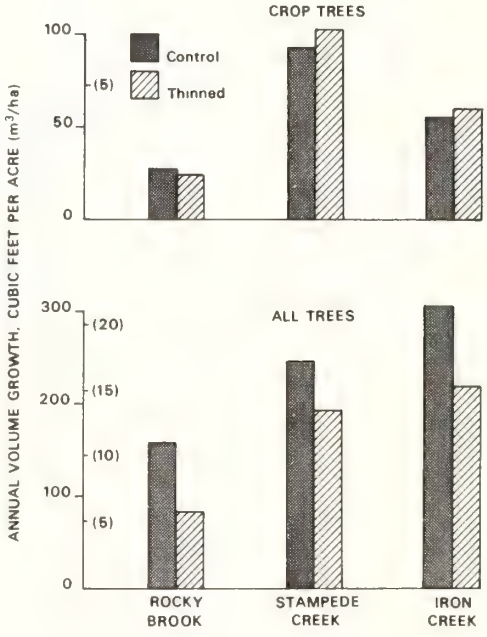


Figure 2.--Calibration period gross growth in cubic volume per acre, per year for three study areas.

At Rocky Brook, a remeasurement was available after 2 years of the calibration period. This measurement showed that growth of all trees on thinned plots was depressed (33 percent of the growth on control plots) during the first 2 years after thinning, then improved (66 percent of control) during the last 4 years, averaging 52 percent for the total period.

Growth at Iron Creek would be somewhat higher if stand age was more comparable to those at the other two areas. Stand ages at Stampede Creek and Rocky Brook are near those at which culmination of periodic annual growth in cubic feet occurs. Stand age at Iron Creek is much below that where culmination occurs.

Since no thinned plot has cubic volume growth even approaching that of its associated control plots, it is useless to speculate now on which stand will end up giving the best response to thinning in terms of absolute growth. Comparisons of absolute growth are confounded by differences in stand age, site index, mortality either before or immediately after the calibration cut, and intensity of the calibration cut. I will assume for now that response can be estimated by the ratio of growth percents for thinned and unthinned stands--(thinned stand growth/thinned stand growing stock)/(control growth/control growing stock). With no response or depression, this ratio would be nearly 1.00.[4/]

In spite of the especially heavy cut and severe snow damage at Rocky Brook, response in cubic volume growth (total stem) to thinning here has been about as good as that at the Stampede Creek area. The ratios for the three areas are 1.23, 1.26, and 1.14 for Rocky Brook, Stampede Creek, and Iron Creek, respectively. In absolute terms, though, growth in these young stands increases with site index and age.

CROP TREES

The remeasurement at Rocky Brook in 1965 showed that volume growth of crop trees in all thinned plots declined relative to that of crop trees in the control plots in the first 2 years (1964-65) of the calibration period (table 11, p. 22). This may be a consequence of the environmental stress of the calibration thinning and crown damage from heavy snow. In the last 4 years (1966-69), growth differences were slight. It may seem contradictory that crop trees in thinned plots at Rocky Brook grew a little less than those in control plots, whereas growth percents for the total stands indicate growth response for all trees in thinned stands. The explanation, which may involve different growth response by different tree sizes, will be discussed later under "Growth Efficiency of Individual Trees" (p. 7).

At Stampede Creek and Iron Creek, where intensity of calibration thinning was lighter than at Rocky Brook, crop tree growth in thinned stands was 11 and 15 percent, respectively, better than growth in associated control stands (tables 12 and 13, p. 22, 23).

Basal Area

ALL TREES

Reductions in basal area growth of thinned stands at all three areas were proportionately quite comparable to their reductions in cubic volume growth (tables 8, 9, 10, p. 17 , 19 , 20).

At Rocky Brook, just as with cubic volume growth, there was a greater reduction in the first 2 years of the calibration period than in the last 4 years.

Results from these three study areas (tables 7, 8, 9, p. 16 , 17 , 19) illustrate

[4/] With no response or depression, this ratio would be exactly 1.00 if all trees grew at the same rate. In fact, they do not, but these ratios do indicate relative response between study areas since all areas were thinned the same way.

how difficult it can be to predict volume growth response via basal area growth response, when the technique described above for volume growth response is used. At Rocky Brook, basal area and volume growth responses were 1.31 and 1.23, respectively, so basal area growth slightly overestimated volume growth. At Stampede Creek, basal area growth response greatly overestimated volume growth response, with values of 1.46 and 1.26, respectively. The overestimate at Iron Creek was moderate, with response values of 1.28 and 1.14. It is interesting to note that, in all cases, basal area response overestimated volume growth response.

CROP TREES

As for "All Trees," crop trees in thinned stands at Rocky Brook showed a decline in growth the first 2 years of the calibration period. During the last 4 years, growth was virtually the same as for crop trees in control stands (table 11, p. 22).

Crop trees in thinned stands at Stampede Creek and Iron Creek grew moderately better than crop trees in control plots (tables 12, 13, p. 22 , 23).

Also as for "All Trees," basal area growth has been a poor predictor of volume growth.

Height Growth

Height growth of crop trees in thinned stands at Rocky Brook is improving after a decline the first 2 years (fig. 3 and table 14, p. 23). Control crop trees grew only 70 percent as much in height in the last 4 years of the calibration period as did crop trees in the thinned stands. The differences in height growth are not statistically significant ($p \leq 0.05$), but I think the treatment means are valid indicators of height growth response. The initial decline in the thinned stands is probably due to

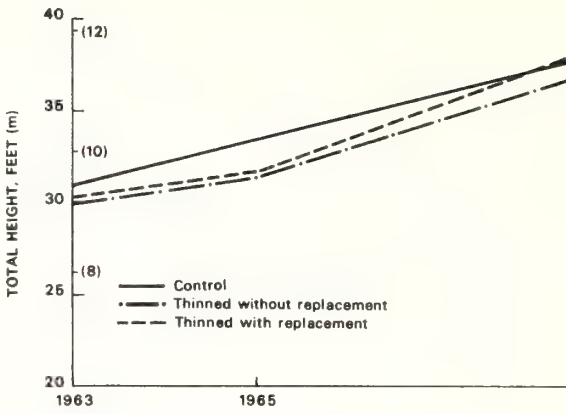


Figure 3.--Total height during the calibration period for thinned and control plots, crop trees only, Rocky Brook.

"shock" and agrees with results at another low-site area (Staebler 1956). No such decrease in height growth of crop trees on thinnned plots at Iron Creek and Stampede Creek has been observed (tables 15, 16, p. 24 , 25).

Diameter Breast High

Diameter growth trends are as expected (fig. 4 and tables 8, 9, 10, 11, 12, 13, p. 17, 19, 20 , 22 , 22 , 23), increasing with increasing site index, showing substantial improvement in thinned stands when considering all trees, and slight improvements for crop trees in thinned stands. The reduction of average diameter growth of all trees in control plots at Stampede Creek relative to that at Rocky Brook is probably due to greater stand age, greater average tree size, and more severely suppressed trees.

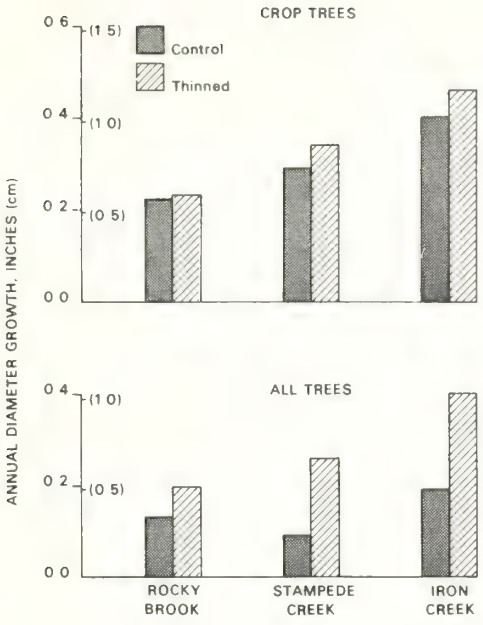


Figure 4.--Calibration period gross growth in quadratic mean diameter per year for three study areas.

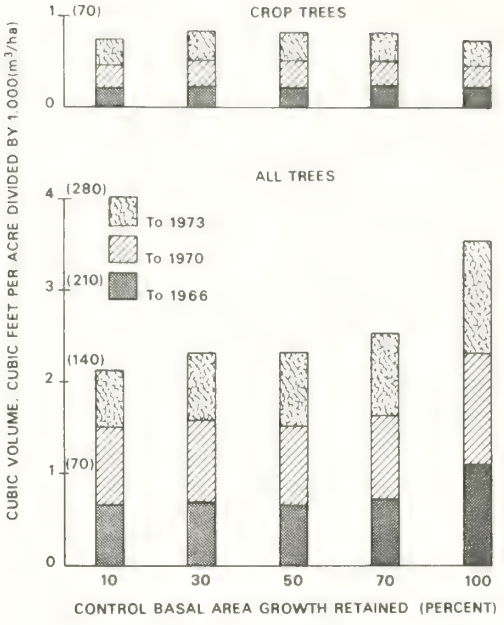


Figure 5.--Gross cubic volume yield by treatments and measurement period, for Iron Creek area.

GROWTH DURING FIRST TREATMENT PERIOD AT IRON CREEK

Cubic Volume

ALL TREES

As expected, the total yield of control plots at this early stage of the experiment is outstripping that of thinned plots (fig. 5 and table 10, p. 20). Gross cubic volume growth among thinned plots is proportional to growing stock (fig. 6). Even though it appeared to me that mortality since the calibration thinning reduced site occupancy to an unknown degree on some plots (primarily in treatments 3 and 4), any effect of this reduction is not apparent in figure 6. This trend (fig. 6) is statistically highly significant ($p \leq 0.01$). Consequently, there is no significant trend in volume growth percent (fig. 7 and table 10, p. 20).

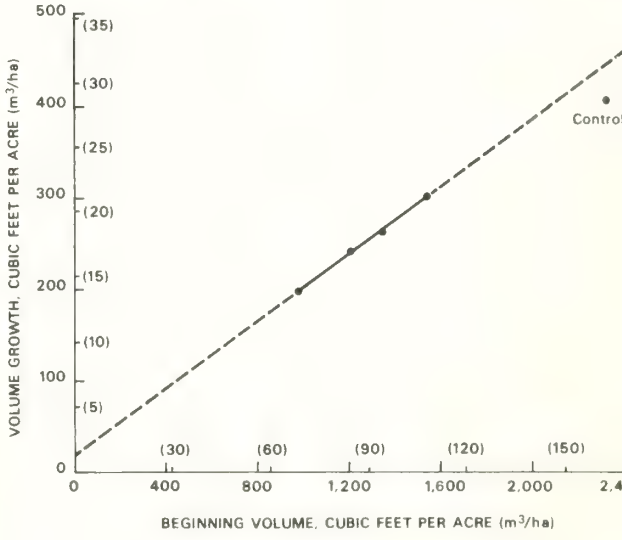


Figure 6.--Annual gross cubic volume growth during the first treatment period related to growing stock at start of the period, Iron Creek area.

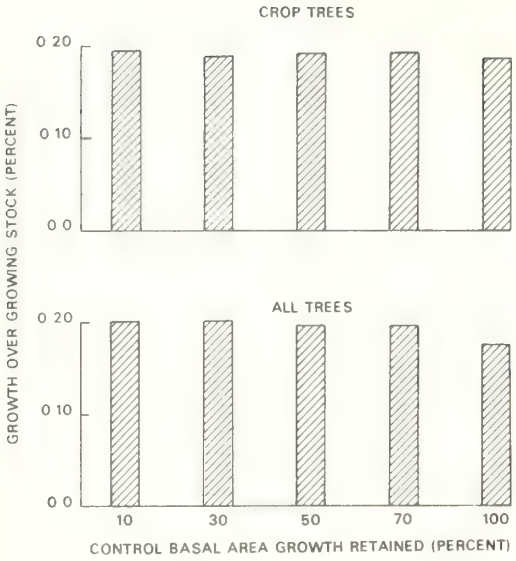


Figure 7.--First treatment period (1970-73) gross volume growth divided by volume at start of period by treatments, for Iron Creek area.

These results mean that trees are essentially free growing in all the thinned stands. Thus, growth has been proportional to growing stock, another indication of the overriding influence of the calibration thinning.

Growth percent of control plots is slightly less than that for thinned stands; thus competition in control plots is probably beginning.

CROP TREES

There are no significant differences between treatments in volume growth of crop trees (fig. 5 and table 13, p. 23) nor in their volume growth percent (fig. 7). This illustrates, as with the "all trees" category, the lack of competition thus far in thinned stands at Iron Creek.

Basal Area

ALL TREES

There has been a highly significant ($p \leq 0.01$) linear trend in basal area growth with respect to starting basal area during the first treatment period (fig. 8 and table 10, p. 20), as well as a highly significant negative linear trend in basal area growth percent (fig. 9). One might infer from this trend in growth percent that growth efficiency in these stands improves as stands go from dense to open. Since this contradicts the results for volume growth, above, we see, again, as in the calibration period, that basal area growth can be a poor predictor of volume growth. On the positive side, basal area growth (like d.b.h. growth) may be a more sensitive indicator of developing competition than is volume growth.

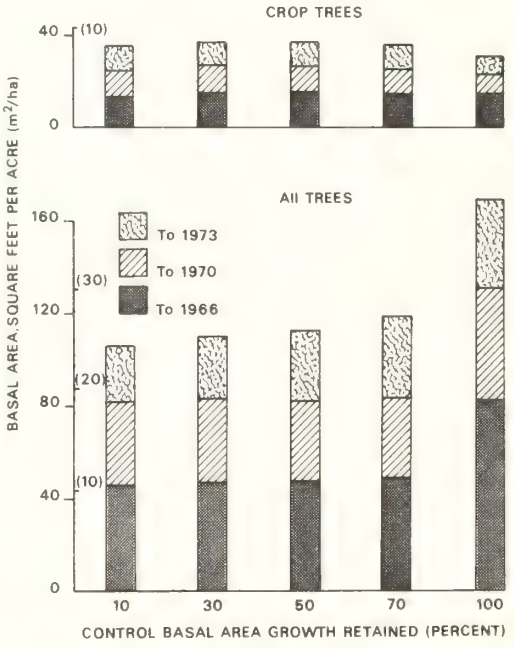


Figure 8.--Gross basal area yield by treatments, by measurement period, for Iron Creek area. Sloping lines connect levels of residual basal area after the first treatment thinning.

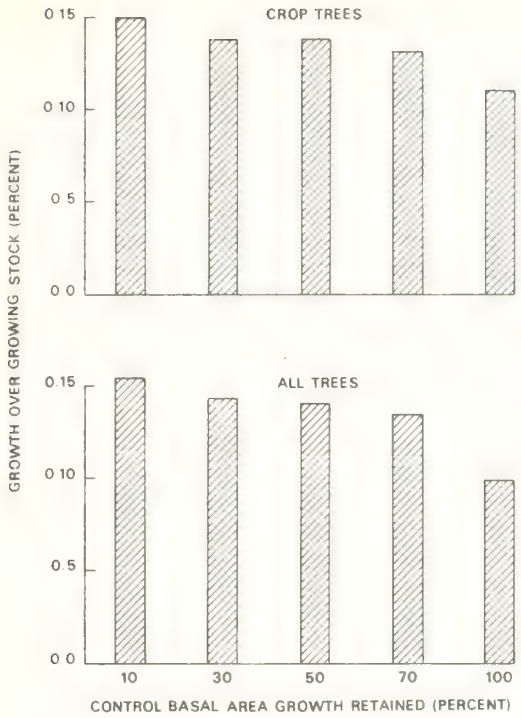


Figure 9.--First treatment period (1970-73) gross basal area growth divided by basal area at start of period, by treatments, for Iron Creek area.

CROP TREES

Basal area growth of crop trees did not differ significantly between thinned and control stands (fig. 8); neither did growth percent of crop trees (fig. 9). This substantiates the general lack of competition in this stand so far. The differences, though statistically insignificant, indicate that competition is about to become a strong influence in control stands.

Diameter Breast High

ALL TREES

Change in quadratic mean diameter has followed a logical, but slight, linear trend among treatments, with the most diameter growth in the most open treatment (table 10, p. 20). This is an indication that competition was just beginning to affect the denser thinned stands. Another indication is that improvement over calibration period growth is generally greater for more open treatments than it is for denser ones.

CROP TREES

Trends for crop trees (table 13, p. 23) have paralleled those for all trees, with slightly more growth in most open treatments when compared with denser ones, and with greater improvement over calibration period growth in more open treatments.

Growth Efficiency of Individual Trees

So far, no definite conclusions can be drawn from the Iron Creek data as to which trees, bigger or smaller initially, are the most efficient producers of volume. I assume efficiency is indicated by periodic volume growth percent, $(V_2 - V_1)/V_1$, where V_1 and V_2 are beginning and ending volumes, respectively. Linear regressions by plots of volume growth percent of individual height-measured trees over their initial volumes for the first treatment period were significant for only 6 of the 24 treated plots. Of the 24 regression coefficients, 20 were negative, including those for the 6 significant ones. This suggests that codominants (the smallest trees left during the calibration thinning) are more efficient producers than dominants. This agrees with results from another study area[5/] and is logical since codominants are under more competitive stress before thinning than are dominants. Codominants possibly responding to thinning more than dominants may explain why growth percent of all trees for thinned stands at Rocky Brook is better than that of controls, in spite of the fact that crop trees (all dominants) in thinned plots grew less than those in control plots.

5/ Study C-8. Data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Because of the impact this result should have on marking guidelines for thinnings, this result should be substantiated over longer periods. Future work will keep track of trends in growth efficiency and, further, relate these trends to individual tree competition indices. All cooperators in the LOGS studies will be involved in this work and will also compare results between study areas to derive growth trends according to site index and stand structure.

Discussion

Which stand will respond best to thinning? This will be difficult to tell, since these stands differ in age, site index, and prethinning stand conditions. The Iron Creek stand is a plantation and so young that all trees, including those on control plots, have been essentially free-growing. Even so, control plot growth has been equivalent to that of site index 210 (McArdle et al. 1961).

The Stampede Creek stand was fairly widely spaced from the start, though stocking was good in 1968. A consequence of the wide and fairly uniform spacing has been amazing growth of control plots similar to that of plantations (Worthington 1961) and also equivalent to that of site index 210.

The Rocky Brook stand, though fairly dense at the start, was still less dense than a normal stand; and control plot growth was like that of site index 110.

What chance does a thinned stand have to look good when "control" stands grow so well? Results thus far argue more for early control of spacing than they do for later thinnings. The future, however, will bring meaningful comparisons of treatment effects on stand volume growth and on how site index influences these effects.

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Appendix I.

Description of Experiment

(as excerpted from Report No. 1)

The experiment is designed to test a number of thinning regimes beginning in young stands made alike at the start through a "calibration" thinning. Thereafter, through the time required for 60 feet of height growth, growing stock is controlled by allowing a specified addition to the growing stock between successive thinnings. Any extra growth is cut and is one of the measured effects of the thinning regime.

EXPERIMENTAL DESIGN

A single experiment consists of eight thinning regimes plus unthinned plots whose growth is the basis for treatment in these regimes. There are three plots per treatment arranged in a completely randomized design for a total of twenty-seven 1/5-acre plots.

Interaction of site quality and treatment can be evaluated by replicating installations on each site quality class. Cooperative effort has made this replication possible.

CROP TREE SELECTION

Well-formed, uniformly spaced, dominant trees at the rate of 80 per acre, or 16 per plot, are designated as crop trees before initial thinning. Each quarter of a plot must have no fewer than three suitable crop trees nor more than five--another criterion for stand uniformity.

INITIAL OR "CALIBRATION" THINNING

All 24 treated plots are thinned initially to the same density to minimize the effect of variations in original density on stand growth. Density of residual trees is controlled by quadratic mean diameter (diameter of tree of average basal area) of the residual stand according to the formula:

Average spacing in feet
= 0.6167 (quadratic mean d.b.h.) + 8.

If one concentrates on leaving a certain amount of basal area corresponding to an estimated overall quadratic mean d.b.h. ($\overline{D}q$), then the residual number of trees may vary freely and the actual $\overline{D}q$'s may vary ± 10 percent between plots. Alternatively, if emphasis is on leaving a certain number of trees corresponding to an estimated overall $\overline{D}q$, then the basal area may vary and the actual $\overline{D}q$'s may vary ± 15 percent between plots.

TREATMENTS

The eight thinning regimes differ in the amount of basal area allowed to accumulate in the growing stock. The amount of growth retained at any thinning is a predetermined percentage of the gross increase found in the unthinned plots since the last thinning (table inside front cover). The average residual basal area for all thinned plots after the calibration thinning is the foundation upon which all future growing stock accumulation is based. As used in the study, control plots may be thought of as providing a "local gross yield table" for the study area.

CONTROL OF THINNING INTERVAL

Thinnings will be made after the calibration thinning whenever average height growth of crop trees comes closest to each multiple of 10 feet.

CONTROL OF TYPE OF THINNING

As far as possible, type of thinning is eliminated as a variable in the

treatment thinnings through several specifications:

1. No crop tree may be cut until all noncrop trees have been cut (another tree may be substituted for a crop tree damaged by logging or killed by natural agents).
2. The quadratic mean diameter of cut trees should approximate that of trees that are available for cutting.
3. The diameters of cut trees should be distributed across the full diameter range of trees available for cutting.

The first treatment thinning at Iron Creek, carefully controlled according to study plan specifications, has resulted in a d.b.h. distribution of cut trees (fig. 10) that agrees well with the "free thinning" method described by Braathe (1957). In this method, weaker dominants and codominants are cut to release stronger dominants and codominants. Trees in the lower crown classes may also be cut if required by prescribed cutting intensity.

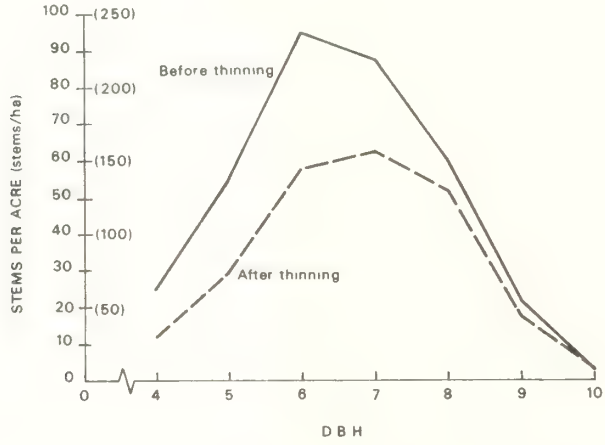

Figure 10.--Number of trees per acre (per hectare) for treatment 4, before and after the first treatment thinning, 1970, Iron Creek area.

TABLE 1. STAND DATA FOR ALL LIVE TREES, BY TREATMENT AND PLOT, AT BEGINNING AND END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK)

TREATMENT AND PLOT NUMBERS		NUMBER TREES PER ACRE				QUADRATIC MEAN D.B.H. (INCHES)				BASAL AREA PER ACRE (SQUARE FEET)				TOTAL STEM VOLUME PER ACRE (CUBIC FEET)			
		START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969
1:	024	400	400	400	395	3.7	4.2	4.2	4.9	30.5	39.1	39.1	51.7	352	476	478	743
	032	400	330	330	320	4.3	4.7	4.7	5.5	35.7	39.6	39.6	52.4	461	517	517	810
	036	400	350	350	350	4.4	4.8	4.8	5.6	43.2	44.6	44.6	59.6	567	661	661	1024
2:	006	395	345			4.0	4.4			33.8	35.7			444	459		
	020	400	385	385	370	3.8	4.4	4.4	5.1	31.7	40.7	40.7	53.2	380	505	505	796
	030	400	340	340	340	4.2	4.9	4.9	5.7	38.9	44.4	44.4	59.2	529	626	626	979
	044			400	380			4.6	5.5			45.6	62.0			587	1082
3:	011	400	400	400	375	4.3	4.8	4.8	5.7	39.7	49.5	49.5	65.5	475	671	671	1053
	016	400	385	385	375	3.9	4.3	4.3	5.0	32.8	39.7	39.7	51.8	394	494	494	737
	031	400	315			4.0	4.7			35.0	38.6			468	529		
	040			400	400			4.6	5.3			46.2	61.0			559	943
4:	010	400	395	395	375	4.3	4.8	4.8	5.6	39.6	49.4	49.4	64.3	499	654	654	1017
	013	400	400	400	400	4.0	4.5	4.5	5.1	35.3	44.7	44.7	56.7	441	582	582	868
	019	400	355	355	330	4.1	4.7	4.7	5.6	36.6	42.8	42.8	55.5	516	609	609	988
5:	009	400	395	395	385	4.0	4.5	4.5	5.1	34.7	42.9	42.9	53.5	414	531	531	789
	015	400	385	385	370	4.0	4.5	4.5	5.1	34.2	42.1	42.1	53.1	417	547	547	824
	021	400	355	355	355	4.0	4.7	4.7	5.5	34.6	42.9	42.9	58.8	435	557	557	925
6:	008	400	375			4.0	4.4			34.2	39.4			470	567		
	033	390	295			3.7	4.3			29.0	29.5			384	395		
	034	400	335			3.9	4.5			32.8	36.7			453	521		
	041			400	400			4.8	5.6			50.5	68.7			697	1201
	042			400	380			4.5	5.3			44.5	58.9			550	975
	043	335	400	390	390	4.4	4.7	5.4	5.4	35.2	47.1	63.2	62.1	494	613	1072	1039
7:	003	400	315			4.0	4.7			35.3	37.9			451	505		
	025	400	395	395	390	4.0	4.6	4.6	5.3	35.0	45.0	45.0	58.7	433	571	571	869
	035	400	305			4.2	4.9			39.0	40.7			548	557		
	038			400	375			4.4	5.3			42.0	56.5			526	939
	039			400	400			4.6	5.3			45.9	61.0			805	1045
8:	012	400	380	380	380	4.1	4.5	4.5	5.2	35.8	42.4	42.4	55.2	454	550	550	842
	023	400	360	360	355	4.2	4.9	4.9	5.7	38.7	46.9	46.9	62.0	535	690	690	1105
	026	400	365	365	365	4.1	4.7	4.7	5.3	36.0	43.5	43.5	56.4	470	565	565	882
CONTROL:	014	1450	1440	1440	1420	3.1	3.5	3.5	3.9	75.0	95.3	95.3	116.4	838	1155	1155	1594
	027	1190	1150	1150	1150	3.6	4.0	4.0	4.5	83.5	102.4	102.4	128.0	1097	1486	1486	2172
	029	1460	1415	1415	1380	3.6	4.0	4.0	4.3	103.0	123.9	123.9	142.5	1276	1689	1689	2223

TABLE 2. STAND DATA FOR ALL LIVE TREES, BY TREATMENT AND PLOT, AT BEGINNING AND END OF CALIBRATION PERIOD: 1968 AND 1973

(STAMPEDE CREEK)

TREATMENT AND PLOT NUMBERS		NUMBER TREES PER ACRE		QUADRATIC MEAN D.B.H. (INCHES)		BASAL AREA PER ACRE (SQUARE FEET)		TOTAL STEM VOLUME PER ACRE (CUBIC FEET)	
		START 1968	END 1973	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973
1:	041	300	295	6.4	7.8	67.6	98.5	1476	2501
	072	285	285	6.8	8.2	71.8	103.6	1599	2537
	126	295	295	6.4	7.6	66.7	92.9	1355	2306
2:	091	285	280	6.6	7.8	68.0	92.8	1430	2324
	112	295	295	6.3	7.7	64.2	94.2	1331	2289
	113	275	270	6.8	8.3	70.1	100.5	1556	2549
3:	051	295	295	6.6	7.9	71.0	101.8	1541	2567
	103	290	285	6.6	7.9	68.9	96.9	1407	2365
	121	275	275	6.6	8.0	66.3	96.9	1439	2367
4:	071	290	285	6.7	8.1	70.7	102.3	1491	2618
	082	320	305	6.2	7.5	67.1	94.6	1357	2258
	115	270	260	6.9	8.2	69.8	95.1	1468	2409
5:	092	275	270	6.9	8.4	71.7	103.3	1641	2703
	114	275	275	6.6	7.8	64.4	91.7	1361	2254
	125	295	295	6.5	7.7	68.1	94.4	1453	2392
6:	032	340	330	6.0	7.2	66.7	93.9	1359	2182
	101	290	290	6.5	7.9	66.6	98.3	1403	2289
	102	330	325	5.6	7.1	60.7	89.6	1192	2119
7:	062	275	265	6.8	8.2	68.9	97.8	1483	2539
	106	290	290	6.7	7.9	70.5	100.1	1563	2527
	107	270	270	6.7	8.0	67.0	93.6	1585	2446
8:	096	230	230	7.4	8.8	68.9	96.9	1544	2629
	111	275	270	6.4	7.8	62.0	90.5	1340	2164
	116	250	250	7.0	8.3	67.3	93.6	1509	2410
CONTROL:	061	1005	965	4.7	5.4	121.0	153.9	2478	3664
	105	635	815	5.3	5.6	104.0	136.9	2048	3317
	122	1295	1235	4.3	4.9	131.8	164.1	2521	3665

TABLE 3. STAND DATA FOR ALL LIVE TREES, BY TREATMENT AND PLOT, AT BEGINNING AND END OF PERIODS: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK)

TREATMENT AND PLOT NUMBERS		NUMBER TREES PER ACRE				QUADRATIC MEAN D.B.H. (INCHES)				BASAL AREA PER ACRE (SQUARE FEET)				TOTAL STEM VOLUME PER ACRE (CUBIC FEET)			
		PERIODS				PERIODS				PERIODS				PERIODS			
		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT	
		START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973
1:	021	350	345	265	205	4.9	6.4	6.9	8.3	45.0	78.1	52.9	77.7	610	1369	945	1581
	033	360	355	225	210	4.7	6.4	6.6	8.1	44.0	79.5	53.1	75.6	637	1478	998	1660
	051	355	330	240	200	4.6	6.3	6.3	7.8	41.3	70.5	52.8	66.6	553	1263	949	1347
2:	082	360	355	200	195	5.0	6.8	6.9	8.4	49.3	88.1	52.6	74.5	743	1725	1038	1795
	091	365	340	205	160	4.7	6.4	6.7	8.1	44.8	76.5	50.4	65.3	647	1450	971	1461
	101	350	335	180	180	5.2	6.9	7.2	8.7	52.1	88.0	51.1	75.0	814	1727	1017	1682
3:	031	355	350	275	270	4.8	6.3	6.4	7.7	43.9	75.0	61.9	87.1	605	1316	1095	1835
	042	335	335	215	210	5.3	7.0	7.3	8.7	51.0	88.7	62.2	86.8	734	1719	1216	1900
	052	355	335	255	230	4.8	6.4	6.7	8.2	43.9	75.9	61.6	84.2	605	1388	1141	1769
4:	013	335	330	200	190	5.3	7.1	7.5	9.1	51.7	90.6	61.8	85.4	815	1760	1230	1959
	062	385	375	270	250	4.7	6.3	6.5	7.9	45.7	80.6	61.8	85.2	657	1528	1194	1785
	111	350	340	240	225	5.1	6.8	6.9	8.3	49.7	84.5	63.2	84.7	821	1769	1337	2070
5:	012	345	335	275	275	5.1	6.7	6.9	8.2	48.2	82.5	71.4	101.6	740	1605	1403	2305
	041	335	330	255	255	5.3	6.9	7.2	8.6	51.1	85.6	71.3	102.3	773	1670	1403	2337
	072	360	350	300	290	4.9	6.4	6.6	7.8	46.5	79.4	71.3	95.3	686	1489	1345	2066
6:	015	350	335	290	285	4.9	6.6	6.8	8.1	46.3	80.6	72.0	102.3	675	1466	1319	2126
	043	370	350	315	290	4.8	6.4	6.4	7.6	45.9	79.1	71.5	96.1	597	1331	1259	1905
	081	360	345	315	310	4.7	6.4	6.5	7.8	43.9	77.5	72.1	101.7	616	1428	1332	2225
7:	011	345	340	305	305	5.3	6.9	7.0	8.3	52.2	86.5	81.3	114.6	783	1678	1544	2586
	023	355	345	340	335	4.9	6.6	6.6	7.7	46.6	81.3	79.5	109.6	678	1514	1473	2383
	063	375	350	350	310	4.8	6.5	6.5	7.6	48.1	80.4	80.4	102.6	731	1563	1560	2354
9:	014	340	330	290	285	5.3	7.1	7.2	8.6	51.7	89.7	80.8	113.9	812	1712	1544	2534
	053	360	350	345	310	4.9	6.6	6.6	7.6	46.4	82.9	81.6	101.7	676	1562	1537	2151
	073	355	355	305	270	5.1	6.7	6.9	8.3	49.5	87.6	80.4	102.3	802	1727	1604	2373
CONTROL:	022	1175	1255	1255	1200	3.8	4.6	4.6	5.2	93.6	143.0	143.0	177.9	1272	2633	2633	3880
	025	1185	1225	1225	1255	3.6	4.5	4.5	5.1	84.2	132.6	132.8	172.3	1133	2325	2325	3527
	071	1015	1090	1090	1100	3.5	4.3	4.3	4.9	88.7	112.6	112.6	144.0	931	2025	2025	2999

Table 4. Calibration period stand statistics for three Forest Service study areas. All volumes per acre (per hectare).

Statistics	Rocky Brook	Stampede Creek	Iron Creek
S.I.	80	95	127
Total age at establishment	27	32	19
Calibration period	1964-69	1969-73	1967-70
Calibration period annual growth - ft^3 (m^3)			
thinned	83 (5.80)	253 (17.70)	219 (15.32)
control	159 (11.13)	340 (23.79)	304 (21.27)
thinned ÷ control X 100	52	74	72
Cubic volume at start of calibration period			
thinned	458 (32.05)	1,200 (83.98)	700 (48.99)
control	1,070 (74.88)	2,010 (140.66)	1,120 (78.38)
thinned ÷ control X 100	43	60	62

TABLE 5. PERIODIC ANNUAL MORTALITY OF ALL TREES, BY TREATMENT, FROM BEGINNING TO END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK AREA. QUADRATIC MEAN D.B.H. IS PERIODIC.)

TREATMENT NUMBERS	NUMBER TREES PER ACRE (ROUNDED TO NEAREST WHOLE TREE)		QUADRATIC MEAN D.B.H. (INCHES)		BASAL AREA PER ACRE (SQUARE FEET)		TOTAL STEM VOLUME PER ACRE (CUBIC FEET)	
	1963-1965	1965-1969	1963-1965	1965-1969	1963-1965	1965-1969	1963-1965	1965-1969
1	20	1	3.6	4.3	1.44	.11	17.2	1.4
2	21	3	3.6	4.6	1.46	.33	16.6	4.9
3	16	3	3.3	3.6	.98	.20	11.7	2.7
4	9	4	3.6	4.2	.56	.36	7.0	5.3
5	11	2	3.3	3.6	.66	.15	7.6	1.7
6	31	3	3.5	3.4	2.04	.16	23.9	2.1
7	31	3	3.4	3.5	2.00	.17	22.2	2.1
8	16	1	3.6	4.1	1.13	.04	13.8	.6
CONTROL	16	5	3.0	2.5	.76	.16	9.6	1.9

TABLE 6. PERIODIC ANNUAL MORTALITY OF ALL TREES, BY TREATMENT, FROM BEGINNING TO END OF CALIBRATION PERIOD: 1968 TO 1973

(STAMPEDE CREEK AREA. QUADRATIC MEAN D.B.H. IS PERIODIC.)

TREATMENT NUMBERS	NUMBER TREES PER ACRE (ROUNDED TO NEAREST WHOLE TREE)	QUADRATIC MEAN D.B.H. (INCHES)	BASAL AREA PER ACRE (SQUARE FEET)	TOTAL STEM VOLUME PER ACRE (CUBIC FEET)
1	0	6.3	.07	1.5
2	1	6.4	.15	3.6
3	0	6.3	.07	1.5
4	2	5.9	.37	7.8
5	0	3.7	.02	.4
6	1	4.9	.13	2.6
7	1	4.5	.07	1.4
8	0	3.0	.02	.2
CONTROL	14	2.3	.41	5.7

TABLE 7. PERIODIC ANNUAL MORTALITY OF ALL TREES, BY TREATMENT AND PERIODS: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK AREA. QUADRATIC MEAN D.B.H. IS PERIODIC.)

TREATMENT NUMBERS	NUMBER TREES PER ACRE (ROUNDED TO NEAREST WHOLE TREE)		QUADRATIC MEAN D.B.H. (INCHES)		BASAL AREA PER ACRE (SQUARE FEET)		TOTAL STEM VOLUME PER ACRE (CUBIC FEET)	
	1966-1970	1970-1973	1966-1970	1970-1973	1966-1970	1970-1973	1966-1970	1970-1973
1	3	6	4.4	6.6	.30	1.46	4.6	28.0
2	4	3	5.0	7.7	.52	1.07	6.7	24.1
3	2	4	4.4	6.4	.22	.92	3.3	18.5
4	2	5	4.6	6.9	.26	1.30	4.4	28.9
5	2	1	4.8	8.2	.26	.41	4.5	8.3
6	4	4	4.3	6.4	.42	.88	6.5	16.4
7	3	5	4.7	6.6	.40	1.20	7.3	26.4
8	2	8	4.5	7.7	.18	2.68	2.9	57.1
CONTROL	7	17	2.5	3.5	.24	1.08	3.5	22.8

TABLE 8. GROSS PERIODIC ANNUAL GROWTH, WITH TOTAL GROWTH AND CUMULATIVE VOLUME YIELD, FOR ALL TREES, IN ENGLISH UNITS, BY TREATMENT, FROM BEGINNING TO END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK)

TREATMENT NUMBERS	QUADRATIC MEAN D.B.H. (INCHES)						BASAL AREA PER ACRE (SQUARE FEET)					
	PERIODIC ANNUAL GROWTH				TOTAL		PERIODIC ANNUAL GROWTH				TOTAL	
	(1963-1965)		(1965-1969)		(1963-1969)		(1963-1965)		(1965-1969)		(1963-1969)	
	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT
1	.20	4.9	.18	3.9	1.1	27	3.8	10.3	3.5	6.5	21.4	59
2	.23	5.8	.19	4.1	1.2	30	4.2	12.1	4.0	9.1	24.3	70
3	.23	5.7	.18	3.9	1.2	29	4.4	12.2	3.8	8.4	23.8	67
4	.25	6.1	.17	3.6	1.2	29	4.8	12.9	3.7	8.0	24.2	65
5	.26	6.5	.16	3.5	1.2	29	4.7	13.7	3.3	7.7	22.6	65
6	.21	5.5	.19	4.1	1.2	31	3.6	11.4	4.2	8.9	24.0	75
7	.23	5.6	.18	4.0	1.2	29	4.4	12.0	3.8	8.5	23.8	65
8	.25	6.1	.17	3.6	1.2	29	4.8	13.1	3.4	7.8	23.4	64
CONTROL	.20	5.8	.10	2.6	.8	23	10.8	12.4	5.6	5.2	44.6	50

TREATMENT NUMBERS	TOTAL STEM VOLUME PER ACRE (CUBIC FEET)							
	PERIODIC ANNUAL GROWTH				TOTAL		CUMULATIVE YIELD [1]	
	(1963-1965)		(1965-1969)		(1963-1969)		(1963-1965)	(1965-1969)
	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT		
1	63	13.7	78	14.2	439	96	586	899
2	56	12.5	100	17.4	512	113	564	963
3	71	16.0	87	15.1	490	110	568	935
4	72	14.8	91	14.8	527	105	629	993
5	69	16.4	77	14.1	446	106	560	866
6	53	12.2	117	19.0	573	132	542	1009
7	56	11.7	98	17.3	503	106	568	961
8	71	14.7	86	14.3	486	100	629	973
CONTROL	196	18.3	140	9.7	953	89	1463	2023

[1] Not included is an estimated 612 cubic feet which was removed during the calibration thinning.

TABLE 8A. GROSS PERIODIC ANNUAL GROWTH, WITH TOTAL GROWTH AND CUMULATIVE VOLUME YIELD, FOR ALL TREES, IN METRIC UNITS, BY TREATMENT, FROM BEGINNING TO END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK)

TREATMENT NUMBERS	QUADRATIC MEAN D.B.H. (CENTIMETERS)						BASAL AREA PER HECTARE (SQUARE METERS)					
	PERIODIC ANNUAL GROWTH				TOTAL		PERIODIC ANNUAL GROWTH				TOTAL	
	(1963-1965)		(1965-1969)		(1963-1969)		(1963-1965)		(1965-1969)		(1963-1969)	
	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT
1	.5	4.9	.5	3.9	2.8	27	.9	10.3	.8	8.5	4.9	59
2	.6	5.8	.5	4.1	3.1	30	1.0	12.1	.9	9.1	5.6	70
3	.6	5.7	.5	3.9	3.0	29	1.0	12.2	.9	8.4	5.5	67
4	.6	6.1	.4	3.6	3.0	29	1.1	12.9	.8	8.0	5.6	65
5	.7	6.5	.4	3.5	2.9	29	1.1	13.7	.8	7.7	5.2	65
6	.5	5.5	.5	4.1	3.0	31	.8	11.4	1.0	8.9	5.5	75
7	.6	5.6	.5	4.0	3.0	29	1.0	12.0	.9	8.5	5.5	65
8	.6	6.1	.4	3.6	3.0	29	1.1	13.1	.8	7.8	5.4	64
CONTROL	.5	5.8	.3	2.6	2.0	23	2.5	12.4	1.3	5.2	10.1	50

TREATMENT NUMBERS	TOTAL STEM VOLUME PER HECTARE (CUBIC METERS)							
	PERIODIC ANNUAL GROWTH				TOTAL		CUMULATIVE YIELD [1/]	
	(1963-1965)		(1965-1969)		(1963-1969)		(1963-1965)	(1965-1969)
	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT		
1	4.4	13.7	5.5	14.2	30.7	96	41.0	62.9
2	3.9	12.5	7.0	17.4	35.8	113	39.4	67.4
3	5.0	16.0	6.1	15.1	34.3	110	41.1	65.5
4	5.0	14.8	6.4	14.8	35.5	105	44.0	69.5
5	4.8	16.4	5.4	14.1	31.2	106	39.2	60.8
6	3.7	12.2	8.2	19.0	40.1	132	37.9	70.6
7	3.9	11.7	6.9	17.3	35.2	106	41.2	68.6
8	5.0	14.7	6.0	14.3	34.0	100	44.0	68.1
CONTROL	13.7	18.3	9.8	9.7	66.7	89	102.4	141.6

[1/] Not included is an estimated 43 cubic meters which was removed during the calibration thinning.

TABLE 9. GROSS PERIODIC ANNUAL GROWTH, WITH CUMULATIVE VOLUME YIELD, IN ENGLISH UNITS, FOR ALL TREES, BY TREATMENT, FROM BEGINNING TO END OF CALIBRATION PERIOD: 1966 TO 1973

(STAMPEDE CREEK)

TREATMENT NUMBERS	QUADRATIC MEAN D.B.H. (INCHES)		BASAL AREA PER ACRE (SQUARE FEET)		TOTAL STEM VOLUME PER ACRE (CUBIC FEET)		
	PERIODIC ANNUAL GROWTH	PERCENT	PERIODIC ANNUAL GROWTH	PERCENT	PERIODIC ANNUAL GROWTH	PERCENT	CUMULATIVE YIELD 1/
1	.26	4.0	6.0	8.7	196	13.3	2456
2	.26	3.9	5.8	8.6	193	13.4	2405
3	.26	3.9	5.9	8.5	196	13.4	2440
4	.26	4.0	6.0	8.7	206	14.3	2467
5	.25	3.8	5.7	8.4	193	13.0	2452
6	.26	4.3	6.0	9.3	178	13.5	2209
7	.26	3.9	5.7	8.4	193	12.5	2511
8	.27	3.9	5.5	8.4	188	12.8	2402
CONTROL	.09	1.9	7.0	5.8	246	10.5	3577

1/ Not included is an estimated 896 cubic feet which was removed during the calibration thinning.

TABLE 9A. GROSS PERIODIC ANNUAL GROWTH, WITH CUMULATIVE VOLUME YIELD, IN METRIC UNITS, FOR ALL TREES, BY TREATMENT, FROM BEGINNING TO END OF CALIBRATION PERIOD: 1968 TO 1973

(STAMPEDE CREEK)

TREATMENT NUMBERS	QUADRATIC MEAN D.B.H. (CENTIMETERS)		BASAL AREA PER HECTARE (SQUARE METERS)		TOTAL STEM VOLUME PER HECTARE (CUBIC METERS)		
	PERIODIC ANNUAL GROWTH	PERCENT	PERIODIC ANNUAL GROWTH	PERCENT	PERIODIC ANNUAL GROWTH	PERCENT	CUMULATIVE YIELD 1/
1	.7	4.0	1.4	8.7	13.7	13.3	171.9
2	.7	3.9	1.3	8.6	13.5	13.4	168.3
3	.7	3.9	1.4	8.5	13.7	13.4	170.8
4	.7	4.0	1.4	8.7	14.4	14.3	172.6
5	.6	3.8	1.3	8.4	13.5	13.0	171.6
6	.7	4.3	1.4	9.3	12.5	13.5	154.6
7	.7	3.9	1.3	8.4	13.5	12.5	175.7
8	.7	3.9	1.3	8.4	13.1	12.8	168.1
CONTROL	.2	1.9	1.6	5.8	17.2	10.5	250.3

1/ Not included is an estimated 62 cubic meters which was removed during the calibration thinning.

TABLE 10. GROSS PERIODIC ANNUAL GROWTH, WITH TOTAL GROWTH AND CUMULATIVE VOLUME YIELD, FOR ALL TREES, IN ENGLISH UNITS, BY TREATMENT AND PERIODS: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK)

QUADRATIC MEAN D.B.H. (INCHES)

TREATMENT NUMBERS	PERIODIC ANNUAL GROWTH PERIODS				TOTAL	
	CALIBRATION (1966-1970)		1ST TREATMENT (1970-1973)		(1966-1973)	
	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT
1	.40	8.4	.46	7.0	3.0	63
2	.41	8.2	.48	6.9	3.1	62
3	.40	8.1	.45	5.7	2.9	60
4	.41	8.2	.45	6.5	3.0	60
5	.40	7.9	.43	6.3	2.9	57
6	.40	8.3	.43	6.6	2.9	60
7	.40	8.0	.41	5.1	2.8	56
8	.42	8.3	.43	6.3	3.0	59
CONTROL	.19	5.2	.18	4.0	1.3	36

BASAL AREA PER ACRE (SQUARE FEET)

TREATMENT NUMBERS	PERIODIC ANNUAL GROWTH PERIODS				TOTAL	
	CALIBRATION (1966-1970)		1ST TREATMENT (1970-1973)		(1966-1973)	
	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT
1	8.5	19.3	8.3	15.6	58.6	135
2	9.4	19.3	7.8	15.2	61.0	125
3	8.6	18.6	9.0	14.5	61.4	133
4	9.3	19.0	8.9	14.3	63.9	130
5	8.8	18.0	9.9	13.8	64.7	133
6	8.8	19.5	10.3	14.3	66.2	146
7	9.0	18.3	10.7	13.3	68.1	139
8	9.6	19.4	11.0	13.6	71.3	145
CONTROL	12.1	14.7	12.8	9.9	86.8	106

TOTAL STEM VOLUME PER ACRE (CUBIC FEET)

TREATMENT NUMBERS	PERIODIC ANNUAL GROWTH PERIODS				TOTAL	
	CALIBRATION (1966-1970)		1ST TREATMENT (1970-1973)		(1966-1973)	
	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT
1	197	32.9	216	22.4	1439	240
2	234	31.6	236	23.4	1644	224
3	213	32.4	246	21.4	1578	244
4	235	30.7	257	20.5	1710	224
5	218	29.6	293	21.2	1753	239
6	206	32.6	277	21.3	1656	263
7	221	30.2	331	21.6	1874	257
8	229	30.0	329	21.5	1876	246
CONTROL	306	27.5	405	17.5	2439	219

CUMULATIVE YIELD [1/]

TREATMENT NUMBERS	PERIODS	
	CALIBRATION (1966-1970)	1ST TREATMENT (1970-1973)
1	1389	2038
2	1669	2378
3	1487	2227
4	1703	2474
5	1606	2486
6	1454	2286
7	1613	2605
8	1678	2639
CONTROL	2335	3551

[1/] Not included is an estimated 412 cubic feet which was removed during the calibration thinning.

TABLE 10A. GROSS PERIODIC ANNUAL GROWTH, WITH TOTAL GROWTH AND CUMULATIVE VOLUME YIELD, FOR ALL TREES, IN METRIC UNITS, BY TREATMENT AND PERIODS: 1966 TO 1973 AND 1970 TO 1973

(IRON CREEK)

QUADRATIC MEAN D.B.H. (CENTIMETERS)

TREATMENT NUMBERS	PERIODIC ANNUAL GROWTH PERIODS				TOTAL	
	CALIBRATION (1966-1970)		1ST TREATMENT (1970-1973)		(1966-1973)	
	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT
1	1.0	8.4	1.2	7.0	7.8	63
2	1.0	8.2	1.2	6.9	7.8	62
3	1.0	8.1	1.1	6.7	7.5	60
4	1.0	8.2	1.1	6.5	7.6	60
5	1.0	7.9	1.1	6.3	7.3	57
6	1.0	8.3	1.1	6.6	7.3	60
7	1.0	8.0	1.0	6.1	7.2	56
8	1.1	8.3	1.1	6.3	7.5	59
CONTROL	.5	5.2	.5	4.0	3.3	36

BASAL AREA PER HECTARE (SQUARE METERS)

TREATMENT NUMBERS	PERIODIC ANNUAL GROWTH PERIODS				TOTAL	
	CALIBRATION (1966-1970)		1ST TREATMENT (1970-1973)		(1966-1973)	
	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT
1	1.9	19.5	1.9	15.6	13.4	135
2	2.2	19.3	1.8	15.2	14.0	125
3	2.0	18.6	2.1	14.5	14.1	133
4	2.1	19.0	2.0	14.3	14.7	130
5	2.0	18.0	2.3	13.8	14.8	133
6	2.0	19.5	2.4	14.3	15.2	146
7	2.1	18.3	2.5	13.3	15.6	139
8	2.2	19.4	2.5	13.6	16.4	145
CONTROL	2.8	14.7	2.9	9.9	19.9	106

TOTAL STEM VOLUME PER HECTARE (CUBIC METERS)

TREATMENT NUMBERS	PERIODIC ANNUAL GROWTH PERIODS				TOTAL		CUMULATIVE YIELD [1/] PERIODS	
	CALIBRATION (1966-1970)		1ST TREATMENT (1970-1973)		(1966-1973)		CALIBRATION (1966-1970)	1ST TREATMENT (1970-1973)
	GROWTH	PERCENT	GROWTH	PERCENT	GROWTH	PERCENT		
1	13.8	32.9	15.1	22.4	100.7	240	97.2	142.6
2	16.3	31.8	16.5	23.4	115.0	224	116.8	160.4
3	14.7	32.4	17.2	21.4	110.4	244	104.1	155.6
4	16.4	30.7	16.3	20.5	119.7	224	119.2	173.1
5	15.3	29.8	20.5	21.2	122.6	239	112.4	173.9
6	14.4	32.8	19.4	21.3	115.9	263	101.7	159.9
7	15.4	35.2	23.1	21.6	131.2	257	112.9	182.3
8	16.3	30.3	22.4	20.5	131.3	246	117.4	184.7
CONTROL	21.4	27.5	26.4	17.5	170.7	219	163.4	248.5

[1/] Not included is an estimated 29 cubic meters which was removed during the calibration thinning.

TABLE 11. GROSS PERIODIC ANNUAL GROWTH, WITH CUMULATIVE VOLUME YIELD, IN ENGLISH UNITS, FOR CROP TREES, BY TREATMENT, FROM BEGINNING TO END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK)

TREATMENT NUMBERS	QUADRATIC MEAN D.B.H. (INCHES) PERIODIC ANNUAL GROWTH		BASAL AREA PER ACRE (SQUARE FEET) PERIODIC ANNUAL GROWTH		TOTAL STEM VOLUME PER ACRE (CUBIC FEET) PERIODIC ANNUAL GROWTH		TOTAL STEM VOLUME PER ACRE (CUBIC FEET) CUMULATIVE YIELD	
	(1963-1965)	(1965-1969)	(1963-1965)	(1965-1969)	(1963-1965)	(1965-1969)	(1963-1965)	(1965-1969)
1	.23	.21	1.0	.9	17	23	157	247
2	.28	.23	1.2	1.2	19	32	171	299
3	.27	.20	1.2	1.0	17	24	171	267
4	.29	.18	1.3	.9	20	23	168	262
5	.31	.18	1.3	.8	20	22	157	246
6	.23	.24	.9	1.2	16	35	150	292
7	.27	.21	1.2	1.0	17	28	173	285
8	.29	.19	1.3	.9	19	25	177	277
CONTROL	.32	.17	1.6	1.0	29	26	236	342

TABLE 12. GROSS PERIODIC ANNUAL GROWTH, WITH CUMULATIVE VOLUME YIELD, IN ENGLISH UNITS, FOR CROP TREES, BY TREATMENT, FROM BEGINNING TO END OF CALIBRATION PERIOD: 1968 TO 1973

(STAMPEDE CREEK)

TREATMENT NUMBERS	QUADRATIC MEAN D.B.H. (INCHES) PERIODIC ANNUAL GROWTH	BASAL AREA PER ACRE (SQUARE FEET) PERIODIC ANNUAL GROWTH	TOTAL STEM VOLUME PER ACRE (CUBIC FEET) PERIODIC ANNUAL GROWTH	TOTAL STEM VOLUME PER ACRE (CUBIC FEET) CUMULATIVE YIELD
1	.33	2.7	94	1182
2	.35	3.0	108	1340
3	.33	2.7	97	1191
4	.35	2.8	104	1216
5	.35	3.0	117	1471
6	.35	2.7	85	1072
7	.34	2.7	99	1236
8	.36	3.1	118	1416
CONTROL	.29	2.4	93	1254

TABLE 13. GROSS PERIODIC ANNUAL GROWTH, WITH CUMULATIVE VOLUME YIELD, IN ENGLISH UNITS, FOR CROP TREES, BY TREATMENT AND PERIODS: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK)

TREATMENT NUMBERS	QUADRATIC MEAN D.B.H. (INCHES)		BASAL AREA PER ACRE (SQUARE FEET)		TOTAL STEM VOLUME PER ACRE (CUBIC FEET)			
	PERIODIC ANNUAL GROWTH PERIODS		PERIODIC ANNUAL GROWTH PERIODS		PERIODIC ANNUAL GROWTH PERIODS		CUMULATIVE YIELD PERIODS	
	CALIBRATION (1966-1970)	1ST TREATMENT (1970-1973)	CALIBRATION (1966-1970)	1ST TREATMENT (1970-1973)	CALIBRATION (1966-1970)	1ST TREATMENT (1970-1973)	CALIBRATION (1966-1970)	1ST TREATMENT (1970-1973)
1	.45	.51	2.5	3.6	62	100	449	749
2	.44	.51	2.6	3.8	69	116	514	864
3	.47	.49	2.8	3.6	71	101	512	817
4	.47	.49	2.8	3.7	76	109	555	882
5	.47	.49	2.9	3.7	76	116	563	911
6	.47	.50	2.7	3.6	65	101	466	770
7	.45	.45	2.5	3.2	63	103	468	776
8	.50	.49	3.0	3.6	76	111	550	884
CONTROL	.40	.39	2.2	2.6	61	86	459	717

TABLE 14. MEAN HEIGHT OF CROP TREES BY TREATMENT AND MEASUREMENT YEAR: 1963, 1965, AND 1969

(ROCKY BROOK)

TREATMENT NUMBERS	NUMBER TREES MEASURED			MEAN HEIGHT (FEET)		
	1963	1965	1969	1963	1965	1969
1	23	18	20	29.3	32.1	38.2
2	20	12	17	31.3	31.6	40.4
3	24	13	21	31.0	31.2	37.4
4	21	15	17	31.7	33.1	39.7
5	25	23	23	27.8	30.3	36.2
6	20	13	25	31.6	33.9	42.1
7	24	13	21	30.3	30.5	39.0
8	26	17	18	31.0	31.5	36.8
CONTROL	18	12	13	31.0	33.5	36.5
ALL TREATMENTS	201	136	175	30.5	31.9	36.9
STANDARD DEVIATION				1.23	1.20	1.70
COEFFICIENT OF VARIATION (PERCENT)				4.0	3.8	4.4
THINNED TREATMENTS ONLY	183	124	162	30.4	31.7	39.3

TABLE 15. MEAN HEIGHT OF CROP TREES, BY TREATMENT, AT BEGINNING AND END OF CALIBRATION PERIOD: 1968 AND 1973

(STAMPEDE CREEK)

TREATMENT NUMBERS	NUMBER TREES MEASURED		MEAN HEIGHT (FEET)	
	1968	1973	1968	1973
1	11	19	56.2	67.3
2	13	16	56.5	67.0
3	12	14	55.2	68.0
4	11	16	57.6	68.5
5	14	18	57.1	67.5
6	13	16	55.0	65.1
7	10	16	56.0	67.9
8	10	16	57.9	68.5
CONTROL	12	16	57.7	69.1
ALL TREATMENTS	106	147	56.5	67.6
STANDARD DEVIATION			1.01	1.03
COEFFICIENT OF VARIATION (PERCENT)			1.8	1.6
THINNED TREATMENTS ONLY	94	131	56.4	67.5

TABLE 16. MEAN HEIGHT OF CROP TREES BY TREATMENT AND MEASUREMENT YEAR: 1966, 1970, AND 1973

(IRON CREEK)

TREATMENT NUMBERS	NUMBER TREES MEASURED			MEAN HEIGHT (FEET)		
	1966	1970	1973	1966	1970	1973
1	16	22	21	34.4	45.9	53.5
2	16	22	21	36.4	48.7	56.4
3	16	24	23	34.9	47.0	53.9
4	15	22	23	38.8	50.5	58.5
5	15	22	19	37.6	48.9	57.3
6	15	21	22	35.4	45.8	53.2
7	16	24	24	36.7	46.7	55.2
8	15	21	20	38.4	49.6	57.7
CONTROL	14	19	18	35.4	47.5	55.7
ALL TREATMENTS	138	197	191	36.4	47.8	55.7
STANDARD DEVIATION				1.47	1.58	1.83
COEFFICIENT OF VARIATION (PERCENT)				4.0	3.3	3.3
THINNED TREATMENTS ONLY	124	178	173	36.6	47.9	55.7

TABLE 17. STAND DATA FOR ALL LIVE TREES IN ENGLISH UNITS, BY TREATMENT, AT BEGINNING AND END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK)

TREATMENT NUMBERS	NUMBER TREES PER ACRE (ROUNDED TO NEAREST WHOLE TREE)				QUADRATIC MEAN D.B.H. (INCHES)				BASAL AREA PER ACRE (SQUARE FEET)				TOTAL STEM VOLUME PER ACRE (CUBIC FEET)			
	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969
1	400	360	360	355	4.1	4.6	4.6	5.3	36.5	41.1	41.1	54.6	460	552	552	859
2	398	357	375	363	4.0	4.6	4.6	5.4	34.8	40.3	43.6	58.2	451	530	573	952
3	400	367	395	383	4.1	4.6	4.6	5.3	35.8	42.6	45.1	59.4	446	564	575	911
4	400	383	383	368	4.1	4.7	4.7	5.4	37.2	45.6	45.6	58.8	485	615	615	957
5	400	378	378	370	4.0	4.6	4.6	5.2	34.5	42.6	42.6	55.1	422	545	545	846
6	397	335	400	390	3.8	4.4	4.7	5.4	32.0	35.2	47.1	63.2	436	494	613	1072
7	400	338	398	388	4.1	4.7	4.5	5.3	36.4	41.2	44.3	58.7	477	544	567	951
8	400	368	368	367	4.1	4.7	4.7	5.4	36.8	44.2	44.2	57.9	487	602	602	943
CONTROL	1367	1335	1335	1317	3.4	3.8	3.8	4.2	87.2	107.2	107.2	129.0	1070	1443	1443	1996

TABLE 17A. STAND DATA FOR ALL LIVE TREES IN METRIC UNITS, BY TREATMENT, AT BEGINNING AND END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK)

TREATMENT NUMBERS	NUMBER TREES PER HECTARE (ROUNDED TO NEAREST WHOLE TREE)				QUADRATIC MEAN D.B.H. (CENTIMETERS)				BASAL AREA PER HECTARE (SQUARE METERS)				TOTAL STEM VOLUME PER HECTARE (CUBIC METERS)			
	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969
1	988	890	890	877	10.4	11.6	11.6	13.5	8.4	9.4	9.4	12.5	32	39	39	60
2	984	881	927	898	10.2	11.6	11.7	13.8	8.0	9.2	10.0	13.4	32	37	40	67
3	988	906	976	947	10.3	11.7	11.6	13.5	8.2	9.8	10.4	13.6	31	39	40	64
4	988	947	947	910	10.5	11.9	11.9	13.7	8.5	10.5	10.5	13.5	34	43	43	67
5	988	935	935	914	10.1	11.6	11.6	13.3	7.9	9.8	9.8	12.7	30	38	38	59
6	980	828	988	964	9.8	11.2	11.8	13.8	7.3	8.1	10.8	14.5	30	35	43	75
7	988	836	984	960	10.4	12.0	11.5	13.4	8.4	9.5	10.2	13.5	33	38	40	67
8	988	910	910	906	10.4	11.9	11.9	13.7	8.5	10.2	10.2	13.3	34	42	42	66
CONTROL	3377	3299	3299	3254	8.7	9.8	9.8	10.8	20.0	24.6	24.6	29.6	75	101	101	140

TABLE 1B. STAND DATA FOR ALL LIVE TREES IN ENGLISH UNITS, BY TREATMENT, AT BEGINNING AND END OF CALIBRATION PERIOD: 1968 AND 1973

(STAMPEDE CREEK)

TREATMENT NUMBERS	NUMBER TREES PER ACRE 1/		QUADRATIC MEAN D.B.H. (INCHES)		BASAL AREA PER ACRE (SQUARE FEET)		TOTAL STEM VOLUME PER ACRE (CUBIC FEET)	
	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973
1	293	292	6.6	7.9	68.7	98.4	1475	2448
2	285	282	6.6	7.9	67.4	95.8	1439	2387
3	287	285	6.7	8.0	69.4	98.5	1462	2433
4	293	283	6.6	7.9	69.2	97.3	1439	2428
5	282	280	6.7	7.9	68.1	96.5	1485	2450
6	320	315	6.1	7.4	64.7	94.0	1318	2196
7	278	275	6.7	8.1	68.8	97.2	1544	2504
8	252	250	6.9	8.3	66.1	93.7	1464	2401
CONTROL	995	1005	4.7	5.3	118.9	151.6	2349	3548

1/ Rounded to nearest whole tree.

TABLE 1&A. STAND DATA FOR ALL LIVE TREES IN METRIC UNITS, BY TREATMENT, AT BEGINNING AND END OF CALIBRATION PERIOD: 1968 AND 1973

(STAMPEDE CREEK)

TREATMENT NUMBERS	NUMBER TREES PER HECTARE 1/		QUADRATIC MEAN D.B.H. (CENTIMETERS)		BASAL AREA PER HECTARE (SQUARE METERS)		TOTAL STEM VOLUME PER HECTARE (CUBIC METERS)	
	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973
1	725	721	16.8	20.0	15.8	22.6	103	171
2	704	696	16.7	20.1	15.5	22.0	101	167
3	708	704	16.9	20.2	15.9	22.6	102	170
4	725	700	16.7	20.2	15.9	22.3	101	170
5	696	692	16.9	20.2	15.6	22.1	104	171
6	791	778	15.5	18.8	14.8	21.6	92	154
7	688	680	17.1	20.4	15.8	22.3	108	175
8	622	618	17.6	21.1	15.2	21.5	102	168
CONTROL	2459	2483	11.9	13.4	27.3	34.8	164	248

1/ Rounded to nearest whole tree.

TABLE 19. STAND DATA FOR ALL LIVE TREES IN ENGLISH UNITS, BY TREATMENT, AT BEGINNING AND END OF PERIODS: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK)

TREATMENT NUMBERS	NUMBER TREES PER ACRE (ROUNDED TO NEAREST WHOLE TREE)				QUADRATIC MEAN D.B.H. (INCHES)				BASAL AREA PER ACRE (SQUARE FEET)				TOTAL STEM VOLUME PER ACRE (CUBIC FEET)			
	PERIODS				PERIODS				PERIODS				PERIODS			
	CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT	
	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973
1	355	343	223	205	4.7	6.4	6.6	8.1	43.4	76.0	52.9	73.3	600	1370	964	1529
2	358	343	195	185	5.0	6.7	6.9	8.4	48.7	84.2	51.4	71.6	734	1634	1009	1646
3	348	340	248	237	4.9	6.6	6.8	8.2	46.3	79.9	61.9	86.1	648	1474	1151	1834
4	357	348	237	222	5.0	6.7	6.9	8.4	49.0	85.2	62.3	85.1	764	1686	1254	1938
5	347	338	277	273	5.1	6.7	6.9	8.2	48.6	82.6	71.3	99.7	733	1588	1383	2236
6	360	343	307	295	4.8	6.5	6.6	7.9	45.4	79.0	71.9	100.0	629	1428	1303	2085
7	358	345	332	317	5.0	6.7	6.7	7.9	49.0	83.4	80.4	108.9	731	1584	1528	2441
8	352	345	313	288	5.1	6.8	6.9	8.2	49.2	86.7	80.9	105.9	763	1667	1562	2352
CONTROL	1125	1190	1190	1185	3.7	4.5	4.5	5.1	62.2	129.5	129.5	164.7	1112	2321	2321	3469

TABLE 19A. STAND DATA FOR ALL LIVE TREES IN METRIC UNITS, BY TREATMENT, AT BEGINNING AND END OF PERIODS: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK)

TREATMENT NUMBERS	NUMBER TREES PER HECTARE (ROUNDED TO NEAREST WHOLE TREE)				QUADRATIC MEAN D.B.H. (CENTIMETERS)				BASAL AREA PER HECTARE (SQUARE METERS)				TOTAL STEM VOLUME PER HECTARE (CUBIC METERS)			
	PERIODS				PERIODS				PERIODS				PERIODS			
	CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT	
	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973
1	877	848	552	507	12.0	16.2	16.7	20.6	10.0	17.5	12.1	16.8	42	96	67	107
2	885	848	482	457	12.7	17.0	17.7	21.4	11.2	19.3	11.8	16.4	51	114	71	115
3	861	840	614	585	12.5	16.7	17.2	20.7	10.6	18.3	14.2	19.8	45	103	81	128
4	881	861	585	548	12.8	17.0	17.7	21.3	11.3	19.6	14.3	19.5	53	118	88	136
5	857	836	684	675	12.9	17.0	17.5	20.8	11.2	19.0	16.4	22.9	51	111	97	156
6	890	848	756	729	12.2	16.5	16.8	20.0	10.4	18.1	16.5	23.0	44	100	91	146
7	885	853	820	782	12.7	16.9	16.9	20.2	11.3	19.1	18.5	25.0	51	111	107	171
8	869	853	774	712	12.9	17.2	17.5	20.9	11.3	19.9	18.6	24.3	53	117	109	165
CONTROL	2780	2941	2941	2928	9.3	11.4	11.4	12.8	18.9	29.7	29.7	37.8	78	162	162	243

TABLE 20. STAND DATA FOR CROP TREES, BY TREATMENT AND PLOT, AT BEGINNING AND END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK)

TREATMENT AND PLOT NUMBERS		NUMBER TREES PER ACRE				QUADRATIC MEAN D.B.H. (INCHES)				BASAL AREA PER ACRE (SQUARE FEET)				TOTAL STEM VOLUME PER ACRE (CUBIC FEET)			
		START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969
1:	024	80	80	80	80	4.3	4.8	4.8	5.5	8.1	10.1	10.1	13.3	94	122	122	192
	032	75	65	65	60	4.4	5.1	5.1	6.1	7.9	9.2	9.2	12.1	105	125	125	195
	036	80	75	75	75	5.3	5.7	5.7	6.7	12.0	13.3	13.3	18.1	169	210	210	333
2:	006	80	75			4.6	5.0			9.4	10.4			128	140		
	020	75	75	75	75	4.7	5.4	5.4	6.2	9.0	11.8	11.8	15.7	113	158	158	252
	030	80	75	75	75	5.0	5.8	5.8	6.6	11.0	13.5	13.5	17.6	161	205	205	309
	044			60	75			5.6	6.9			13.8	19.4			195	375
3:	011	80	80	80	80	5.0	5.5	5.5	6.3	10.7	13.3	13.3	17.5	147	188	188	289
	016	80	80	80	80	4.6	5.2	5.2	5.9	9.4	11.6	11.6	15.2	128	158	158	241
	031	80	70			4.7	5.4			9.5	11.1			135	157		
	040			80	80			5.4	6.2			12.6	16.5			160	265
4:	010	80	80	80	80	4.7	5.3	5.3	6.1	9.7	12.4	12.4	16.4	125	169	169	267
	013	80	80	80	80	4.4	5.0	5.0	5.6	8.6	10.9	10.9	13.7	110	143	143	214
	019	80	75	75	70	4.8	5.5	5.5	6.3	10.2	12.3	12.3	15.3	151	185	185	285
5:	009	80	75	75	75	4.4	5.1	5.1	5.7	8.6	10.5	10.5	13.3	106	140	140	210
	015	80	75	75	75	4.5	5.1	5.1	5.8	8.9	10.8	10.8	13.8	112	145	145	226
	021	80	75	75	75	4.7	5.6	5.6	6.4	9.8	12.7	12.7	16.9	130	173	173	287
6:	008	80	75			4.4	4.8			8.5	9.5			120	143		
	033	80	45			4.3	5.4			8.1	7.2			113	108		
	034	80	70			4.4	5.2			8.5	10.1			122	152		
	041			60	80			5.7	6.7			14.0	19.5			211	368
	042			80	80			5.1	6.0			11.5	15.6			147	268
	043	63	80	80	80	5.1	5.4	6.4	6.5	8.9	13.0	17.8	18.4	134	181	322	331
7:	003	80	75			4.8	5.3			9.9	11.7			135	166		
	025	80	75	75	70	4.5	5.2	5.2	6.0	8.8	10.9	10.9	13.9	114	142	142	222
	035	80	65			5.1	5.9			11.4	12.2			167	180		
	038			80	80			4.8	5.8			10.2	14.4			133	252
	039			80	80			5.5	6.3			13.1	17.4			189	322
8:	012	80	75	75	75	4.5	5.1	5.1	5.8	8.9	10.6	10.6	13.6	120	146	146	218
	023	80	75	75	70	5.0	5.7	5.7	6.7	10.8	13.3	13.3	17.2	156	203	203	326
	026	80	75	75	75	4.8	5.4	5.4	6.2	9.9	12.1	12.1	15.8	138	166	166	264
CONTROL:	014	80	80	80	80	4.5	5.0	5.0	5.6	8.8	11.1	11.1	13.5	114	154	154	211
	027	80	80	80	80	6.1	6.8	6.8	7.8	16.5	20.4	20.4	26.4	258	340	340	506
	029	80	80	80	80	5.3	5.9	5.9	6.5	12.0	15.2	15.2	18.2	163	215	215	309

TABLE 11. STAND DATA FOR CROP TREES, BY TREATMENT AND PLOT, AT BEGINNING AND END OF CALIBRATION PERIOD: 1968 AND 1973

(STAMPEDE CREEK)

TREATMENT AND PLOT NUMBERS		NUMBER TREES PER ACRE		QUADRATIC MEAN D.B.H. (INCHES)		BASAL AREA PER ACRE (SQUARE FEET)		TOTAL STEM VOLUME PER ACRE (CUBIC FEET)	
		START 1968	END 1973	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973
1:	041	80	80	7.9	9.6	27.3	40.5	648	1116
	072	80	80	8.7	10.4	33.0	47.6	797	1249
	126	80	80	8.3	9.8	29.9	42.0	692	1182
2:	091	80	80	8.6	10.1	31.9	44.7	716	1195
	112	80	80	8.4	10.2	30.4	45.0	707	1232
	113	80	80	9.5	11.4	39.3	56.2	983	1594
3:	051	80	80	8.7	10.3	32.8	46.6	781	1318
	103	80	80	8.3	10.0	30.1	43.5	670	1160
	121	80	80	8.2	9.8	29.1	41.6	665	1097
4:	071	80	80	8.5	10.4	31.7	47.2	719	1296
	082	80	80	7.9	9.6	27.1	39.8	609	1031
	115	80	80	8.6	10.2	32.3	45.9	754	1322
5:	092	80	80	9.2	11.1	37.1	53.7	945	1572
	114	80	80	9.2	10.9	36.8	51.6	860	1449
	125	80	80	8.9	10.5	34.8	48.4	832	1394
6:	032	80	80	7.8	9.4	26.4	38.7	610	994
	101	80	80	8.5	10.4	31.8	46.6	766	1217
	102	80	80	7.7	9.4	25.8	38.9	560	1005
7:	062	80	80	8.6	10.4	32.5	47.6	757	1347
	106	80	80	8.4	10.1	31.0	44.8	735	1234
	107	80	80	8.1	9.7	29.0	40.8	728	1127
8:	096	80	80	9.3	11.1	37.7	53.7	891	1596
	111	80	80	8.9	10.9	34.6	51.4	855	1391
	116	80	80	8.5	10.1	31.6	44.7	735	1260
CONTROL:	061	80	80	8.3	9.8	30.3	41.9	727	1176
	105	80	80	8.8	10.2	33.6	45.3	809	1260
	122	80	80	9.0	10.4	35.1	47.0	834	1325

TABLE 22. STAND DATA FOR CROP TREES, BY TREATMENT AND PLOT, AT BEGINNING AND END OF PERIODS: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK)

TREATMENT AND PLOT NUMBERS		NUMBER TREES PER ACRE				QUADRATIC MEAN D.B.H. (INCHES)				BASAL AREA PER ACRE (SQUARE FEET)				TOTAL STEM VOLUME PER ACRE (CUBIC FEET)			
		PERIODS				PERIODS				PERIODS				PERIODS			
		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT	
		START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973
1:	021	80	80	80	80	5.8	7.7	7.7	9.3	14.8	25.5	25.5	37.8	214	472	472	802
	033	80	80	80	65	5.3	7.1	7.1	8.9	12.5	22.2	22.2	28.4	193	434	434	652
	051	80	70	75	70	5.6	7.6	7.5	9.2	13.6	22.1	23.2	32.2	192	413	432	685
2:	062	80	80	80	75	5.8	7.7	7.7	9.3	14.9	25.5	25.5	35.2	239	523	523	902
	091	80	75	80	65	5.6	7.4	7.3	9.0	13.5	22.2	23.5	28.5	208	444	469	641
	101	80	75	80	80	6.1	8.0	7.9	9.6	16.3	26.3	27.6	40.1	268	543	568	913
3:	031	80	80	80	80	5.7	7.4	7.4	8.8	14.1	23.8	23.8	33.9	209	440	440	745
	042	80	80	80	75	6.2	8.1	8.1	9.6	16.7	28.8	28.8	37.8	249	577	577	833
	052	80	80	80	80	5.8	7.8	7.8	9.3	15.0	26.5	26.3	37.5	224	520	516	814
4:	013	80	80	80	75	6.3	8.2	8.2	9.8	17.2	29.4	29.4	39.1	287	602	602	905
	062	80	75	80	80	5.4	7.3	7.3	8.7	12.8	22.1	23.0	33.2	195	451	466	717
	111	80	80	80	70	6.0	7.9	7.9	9.5	15.7	27.3	27.3	34.1	276	603	603	878
5:	012	80	80	80	80	6.1	8.0	8.1	9.7	16.0	27.7	28.6	40.7	260	563	584	966
	041	80	80	80	80	6.5	8.3	8.3	9.9	18.2	30.2	30.2	42.6	294	627	627	1017
	072	80	80	80	75	5.8	7.6	7.6	9.0	14.4	25.5	25.5	32.9	221	499	499	741
6:	015	80	75	80	80	5.7	7.6	7.4	8.9	14.0	23.4	24.2	34.8	214	443	456	744
	043	80	80	80	80	5.8	7.6	7.6	9.1	14.5	25.3	25.3	36.0	204	466	466	751
	081	80	80	80	80	5.6	7.5	7.5	9.1	13.6	24.6	24.8	35.8	203	478	478	811
7:	011	80	80	80	80	5.9	7.7	7.7	9.1	15.1	25.7	25.7	36.3	231	493	493	834
	023	80	80	80	75	5.6	7.4	7.4	8.7	13.7	24.1	24.1	31.2	206	467	467	698
	063	75	70	80	65	5.6	7.5	7.4	9.1	13.0	21.3	23.7	29.5	215	420	465	699
8:	014	75	70	75	70	6.1	8.3	8.2	9.9	15.4	26.2	27.5	37.7	251	518	544	869
	053	80	80	80	65	5.7	7.7	7.7	9.3	14.3	25.8	25.8	30.3	217	515	515	689
	073	80	80	80	70	6.1	8.1	8.1	9.7	16.0	28.3	28.3	35.9	274	601	601	881
CONTROL:	022	80	80	80	80	5.9	7.3	7.3	8.4	15.0	23.1	23.1	30.7	222	454	454	707
	025	80	80	80	80	5.8	7.4	7.4	8.6	14.4	23.8	23.8	32.1	214	460	460	723
	071	75	75	75	70	5.8	7.5	7.5	8.5	13.8	23.1	23.1	27.3	209	464	464	633

TABLE 23. NUMBER TREES PER ACRE, BY D.B.H. CLASS, FOR TREATMENTS 1, 2, 3, AND 4, FROM BEGINNING TO END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK AREA. NUMBERS ROUNDED TO NEAREST WHOLE TREE)

D.B.H. CLASS (INCHES)	TREATMENT 1				TREATMENT 2				TREATMENT 3				TREATMENT 4			
	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969
1.6 - 2.5	13	0	0	0	15	3	8	0	17	0	3	2	22	0	0	0
2.6 - 3.5	125	63	63	13	153	68	77	23	118	68	73	18	118	88	88	32
3.6 - 4.5	153	137	137	98	140	145	127	118	167	132	148	92	145	110	110	83
4.6 - 5.5	90	112	112	110	65	88	98	83	83	115	108	130	83	113	113	105
5.6 - 6.5	18	42	42	95	23	35	43	75	10	45	53	68	27	53	53	95
6.6 - 7.5	0	7	7	32	2	15	20	33	5	5	8	45	5	15	15	35
7.6 - 8.5	0	0	0	7	0	2	2	27	0	2	0	7	0	3	3	13
8.6 - 9.5	0	0	0	0	0	0	0	3	0	0	0	2	0	0	0	5
TOTAL	400	360	360	355	398	357	375	363	400	367	395	383	400	383	383	368

TABLE 24. NUMBER TREES PER ACRE, BY D.B.H. CLASS, FOR TREATMENTS 5, 6, 7, AND 8, FROM BEGINNING TO END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK AREA. NUMBERS ROUNDED TO NEAREST WHOLE TREE)

D.B.H. CLASS (INCHES)	TREATMENT 5				TREATMENT 6				TREATMENT 7				TREATMENT 8			
	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969	START 1963	END 1965	START 1965	END 1969
1.6 - 2.5	23	2	2	0	18	5	7	0	13	0	10	0	18	0	0	0
2.6 - 3.5	128	63	63	23	163	82	77	33	128	58	75	22	120	77	77	30
3.6 - 4.5	157	162	162	107	147	115	142	92	162	102	142	105	148	117	117	87
4.6 - 5.5	78	103	103	128	62	98	100	112	72	125	122	130	88	100	100	113
5.6 - 6.5	13	40	40	68	7	32	60	82	23	38	42	87	23	53	53	80
6.6 - 7.5	0	8	8	35	0	3	13	53	0	13	8	35	2	22	22	40
7.6 - 8.5	0	0	0	8	0	0	2	10	0	0	0	8	0	0	0	17
8.6 - 9.5	0	0	0	0	0	0	0	8	2	2	0	2	0	0	0	0
TOTAL	400	378	378	370	397	335	400	390	400	338	398	368	400	368	368	367

TABLE 25. NUMBER TREES PER ACRE, BY D.B.H. CLASS, FOR CONTROL PLOTS, FROM BEGINNING TO END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK AREA. NUMBERS ROUNDED TO NEAREST WHOLE TREE)

D.B.H. CLASS (INCHES)	TWO PARTS OF CALIBRATION PERIOD			
	START 1963	END 1965	START 1965	END 1969
1.6 - 2.5	505	362	362	263
2.6 - 3.5	425	435	435	392
3.6 - 4.5	233	245	245	273
4.6 - 5.5	130	152	152	182
5.6 - 6.5	57	95	95	95
6.6 - 7.5	13	32	32	73
7.6 - 8.5	3	13	13	27
8.6 - 9.5	0	2	2	10
9.6 -10.5	0	0	0	2
TOTAL	1367	1335	1335	1317

TABLE 26. NUMBER TREES PER ACRE, BY D.B.H. CLASS AND TREATMENT NUMBER, AT BEGINNING AND END OF CALIBRATION PERIOD: 1968 AND 1973

(STAMPEDE CREEK AREA. NUMBERS ROUNDED TO NEAREST WHOLE TREE)

D.B.H. CLASS (INCHES)	TREATMENTS 1		2		3		4		5		6		7		8		CONTROL	
	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973	START 1968	END 1973
1.6 - 2.5	2	0	2	0	0	0	3	0	7	0	0	0	3	0	5	0	343	318
2.6 - 3.5	18	13	33	12	13	5	20	12	18	13	33	7	12	7	28	12	162	168
3.6 - 4.5	38	22	52	28	40	20	28	17	47	22	67	35	25	18	13	18	133	107
4.6 - 5.5	48	25	42	43	42	33	48	20	55	40	52	50	45	25	32	22	93	100
5.6 - 6.5	48	42	43	48	50	33	62	40	40	47	62	52	57	32	38	32	92	72
6.6 - 7.5	65	37	42	30	73	38	52	58	45	32	48	45	63	37	58	25	78	67
7.6 - 8.5	42	50	27	33	30	55	48	38	28	37	38	48	38	58	33	47	45	72
8.6 - 9.5	23	48	18	20	28	48	23	32	13	37	10	43	18	52	20	32	30	45
9.6 -10.5	5	35	13	28	8	17	8	38	10	12	5	23	8	18	13	20	12	32
10.6 -11.5	2	12	5	13	0	27	0	20	13	18	2	12	8	12	7	22	3	17
11.6 -12.5	2	3	5	12	2	7	0	8	3	10	3	3	0	8	3	12	2	3
12.6 -13.5	0	3	2	5	0	0	0	0	2	8	0	2	0	8	0	7	2	3
13.6 -14.5	0	2	2	5	0	2	0	0	0	2	0	3	0	0	0	3	0	0
14.6 -15.5	0	0	0	2	0	0	0	0	0	3	0	0	0	0	0	0	0	2
15.6 -16.5	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	293	292	285	282	287	285	293	283	282	285	320	315	278	275	252	250	995	1005

TABLE 27. NUMBER TREES PER ACRE, BY D.B.H. CLASS, FOR TREATMENTS 1, 2, 3, AND 4, AT BEGINNING AND END OF EACH TREATMENT PERIOD: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK AREA. NUMBERS ROUNDED TO NEAREST WHOLE TREE)

D.B.H. CLASS (INCHES)	TREATMENT 1				TREATMENT 2				TREATMENT 3				TREATMENT 4			
	PERIODS				PERIODS				PERIODS				PERIODS			
	CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT	
	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973
1.6 - 2.5	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
2.6 - 3.5	62	0	0	0	32	0	0	0	47	5	3	0	43	0	0	0
3.6 - 4.5	103	40	18	3	100	15	5	0	83	33	17	3	100	25	12	2
4.6 - 5.5	123	68	37	10	132	60	18	5	130	43	35	13	110	55	30	10
5.6 - 6.5	48	95	62	30	73	92	48	12	72	110	67	27	77	95	58	18
6.6 - 7.5	18	92	63	38	22	95	68	30	13	73	57	37	25	88	63	37
7.6 - 8.5	0	30	28	48	0	67	48	53	2	58	55	63	2	60	52	55
8.6 - 9.5	0	15	12	43	0	15	7	52	0	13	12	53	0	22	18	58
9.6 -10.5	0	3	3	22	0	0	0	30	0	3	3	32	0	3	3	32
10.6 -11.5	0	0	0	7	0	0	0	3	0	0	0	7	0	0	0	10
11.6 -12.5	0	0	0	3	0	0	0	0	0	0	0	2	0	0	0	0
TOTAL	355	343	223	205	358	343	195	185	348	340	248	237	357	348	237	222

TABLE 28. NUMBER TREES PER ACRE, BY D.B.H. CLASS, FOR TREATMENTS 5, 6, 7, AND 8 AT BEGINNING AND END OF EACH TREATMENT PERIOD: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK AREA. NUMBERS ROUNDED TO NEAREST WHOLE TREE)

D.B.H. CLASS (INCHES)	TREATMENT 5				TREATMENT 6				TREATMENT 7				TREATMENT 8			
	PERIODS				PERIODS				PERIODS				PERIODS			
	CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT	
	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973
1.6 - 2.5	2	0	0	0	2	0	0	3	0	0	0	0	0	0	0	0
2.6 - 3.5	35	5	2	2	45	2	2	0	38	0	0	0	45	2	0	0
3.6 - 4.5	88	22	12	3	125	17	13	2	93	23	23	3	80	27	17	0
4.6 - 5.5	115	45	33	8	115	78	67	15	130	60	57	23	128	60	55	25
5.6 - 6.5	75	93	75	30	63	92	80	57	77	78	73	53	77	65	62	40
6.6 - 7.5	28	100	83	67	10	95	88	60	15	115	112	57	20	95	88	52
7.6 - 8.5	3	45	43	58	0	50	47	67	5	52	50	77	2	68	65	43
8.6 - 9.5	0	23	23	58	0	10	10	62	0	8	8	60	0	27	25	77
9.6 -10.5	0	5	5	35	0	0	0	27	0	8	8	33	0	2	2	33
10.6 -11.5	0	0	0	10	0	0	0	7	0	0	0	7	0	0	0	18
11.6 -12.5	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0
TOTAL	347	338	277	273	360	343	307	295	358	345	332	317	352	345	313	288

TABLE 29. NUMBER TREES PER ACRE, BY D.B.H. CLASS, FOR CONTROL PLOTS, AT BEGINNING AND END OF EACH TREATMENT PERIOD: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK AREA. NUMBERS ROUNDED TO NEAREST WHOLE TREE)

D.B.H. CLASS (INCHES)	PERIODS: CALIBRATION START 1966	CALIBRATION END 1970	1ST TREATMENT START 1970	1ST TREATMENT END 1973
1.6 - 2.5	407	320	320	305
2.6 - 3.5	228	223	223	182
3.6 - 4.5	245	178	178	148
4.6 - 5.5	175	197	197	145
5.6 - 6.5	53	138	138	152
6.6 - 7.5	15	93	93	127
7.6 - 8.5	2	28	28	82
8.6 - 9.5	0	10	10	32
9.6 -10.5	0	2	2	12
10.6 -11.5	0	0	0	2
TOTAL	1125	1190	1190	1185

TABLE 30. STAND DATA FOR CROP TREES IN ENGLISH UNITS, BY TREATMENT, AT BEGINNING AND END OF TWO PARTS OF CALIBRATION PERIOD: 1963 TO 1965 AND 1965 TO 1969

(ROCKY BROOK)

TREATMENT NUMBERS	NUMBER TREES PER ACRE (ROUNDED TO NEAREST WHOLE TREE) START 1963	END 1965	START 1965	END 1969	QUADRATIC MEAN D.B.H. (INCHES) START 1963	END 1965	START 1965	END 1969	BASAL AREA PER ACRE (SQUARE FEET) START 1963	END 1965	START 1965	END 1969	TOTAL STEM VOLUME PER ACRE (CUBIC FEET) START 1963	END 1965	START 1965	END 1969
1	78	73	73	72	4.7	5.2	5.2	6.1	9.3	10.9	10.9	14.3	123	152	152	240
2	78	75	77	75	4.8	5.4	5.6	6.6	9.8	11.9	13.0	17.6	134	168	186	312
3	80	77	80	80	4.8	5.4	5.3	6.1	9.9	12.0	12.5	16.4	137	167	168	265
4	80	78	78	77	4.7	5.3	5.3	6.0	9.5	11.8	11.8	15.1	129	166	166	255
5	80	75	75	75	4.6	5.3	5.3	6.3	9.1	11.3	11.3	14.7	116	153	153	241
6	80	63	80	80	4.4	5.1	5.4	6.4	8.3	8.9	13.0	17.8	118	134	181	322
7	80	72	78	77	4.8	5.4	5.2	6.0	10.0	11.6	11.4	15.2	139	162	155	265
8	80	75	75	73	4.8	5.4	5.4	6.2	9.9	12.0	12.0	15.5	138	172	172	270
CONTROL	80	80	80	80	5.3	6.0	6.0	6.7	12.4	15.6	15.6	19.4	178	236	236	342

TABLE 31. STAND DATA FOR CROP TREES IN ENGLISH UNITS, BY TREATMENT, AT BEGINNING AND END OF CALIBRATION PERIOD: 1968 AND 1973

(STAMPEDE CREEK)

TREATMENT NUMBERS	NUMBER TREES PER ACRE 1/		QUADRATIC MEAN D.B.H. (INCHES)		BASAL AREA PER ACRE (SQUARE FEET)		TOTAL STEM VOLUME PER ACRE (CUBIC FEET)	
	START 1968	END 1973	START 1966	END 1973	START 1968	END 1973	START 1968	END 1973
1	80	80	8.3	10.0	30.0	43.4	713	1182
2	80	80	8.8	10.6	33.9	48.6	802	1340
3	80	80	8.4	10.0	30.6	43.9	705	1191
4	80	80	8.3	10.1	30.3	44.3	694	1216
5	80	80	9.1	10.8	36.2	51.2	885	1471
6	80	80	8.0	9.8	28.0	41.4	645	1072
7	80	80	8.4	10.1	30.8	44.4	740	1236
8	80	80	8.9	10.7	34.6	49.9	827	1416
CONTROL	80	80	8.7	10.1	33.0	44.8	790	1254

1/ Rounded to nearest whole tree.

TABLE 32. STAND DATA FOR CROP TREES IN ENGLISH UNITS, BY TREATMENT, AT BEGINNING AND END OF PERIODS: 1966 TO 1970 AND 1970 TO 1973

(IRON CREEK)

TREATMENT NUMBERS	NUMBER TREES PER ACRE (ROUNDED TO NEAREST WHOLE TREE)				QUADRATIC MEAN D.B.H. (INCHES)				BASAL AREA PER ACRE (SQUARE FEET)				TOTAL STEM VOLUME PER ACRE (CUBIC FEET)			
	PERIODS				PERIODS				PERIODS				PERIODS			
	CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT		CALIBRATION		1ST TREATMENT	
	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973	START 1966	END 1970	START 1970	END 1973
1	80	77	76	72	5.6	7.5	7.4	9.2	13.6	23.3	23.7	32.8	200	440	446	713
2	80	77	80	73	5.8	7.7	7.7	9.3	14.9	24.7	25.5	34.6	238	503	520	819
3	80	80	80	78	5.9	7.8	7.8	9.2	15.2	26.4	26.3	36.4	227	512	511	797
4	80	78	80	75	5.9	7.8	7.8	9.3	15.2	26.3	26.6	35.5	253	552	557	833
5	80	80	80	78	6.1	8.0	8.0	9.5	16.2	27.8	28.1	38.7	258	563	570	908
6	80	78	80	80	5.7	7.6	7.5	9.3	14.8	24.5	24.8	35.5	207	462	466	769
7	78	77	80	73	5.7	7.5	7.5	9.3	13.9	23.7	24.5	32.3	217	460	475	744
8	78	77	78	66	6.0	8.0	8.0	9.6	15.2	26.8	27.2	34.6	247	545	554	813
CONTROL	78	78	78	77	5.8	7.4	7.4	8.5	14.4	23.4	23.4	30.1	215	459	459	687

Study area	*Cooperator*
Skykomish	Forestry Research Center Weyerhaeuser Company Centralia, Washington
Hoskins	School of Forestry Oregon State University Corvallis, Oregon
Rocky Brook	U.S. Forest Service Region 6 and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Clemons	Forestry Research Center Weyerhaeuser Company Centralia, Washington
Francis	Washington State Department of Natural Resources Olympia, Washington
Iron Creek	U.S. Forest Service Region 6 and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Stampede Creek	U.S. Forest Service Region 6 and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Sayward Forest	Canadian Forestry Service Department of the Environment Victoria, British Columbia
Shawnigan Lake	Canadian Forestry Service Department of the Environment Victoria, British Columbia

Consultative services have been provided by the University of Washington, Seattle, and the Bureau of Land Management, U.S. Department of the Interior.

Williamson, Richard L.
1976. Levels-of-growing-stock cooperative study in Douglas-fir. Report No. 4--Rocky Brook, Stampede Creek, and Iron Creek. USDA For. Serv. Res. Pap. PNW-210, 39 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The U.S. Forest Service maintains three of nine installations in a regional, cooperative study of influences of levels-of-growing-stock (LOGS) on stand growth. The effects of calibration thinnings are described for the three areas. Results of first treatment thinning are described for one area.

KEYWORDS: Thinnings, stand growth, Douglas-fir, *Pseudotsuga menziesii*.

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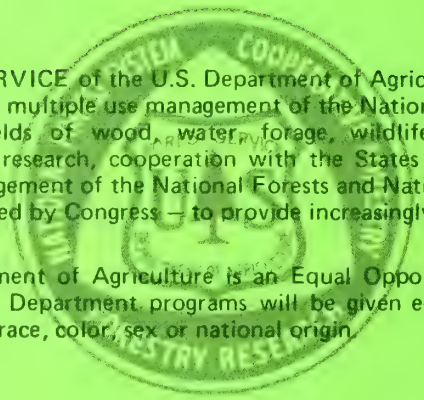
P.O. Box 3141
Portland, Oregon 97208

GPO 997-289



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1976
USDA Forest Service Research Paper PNW-211

EVALUATION TECHNIQUES FOR INTERPRETATION: Study Results From an Exhibition on Energy

J. Alan Wagar
Gregory W. Lovelady
Harlan Falkin

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

THE AUTHORS

At the time of this study, J. Alan Wagar was leader of the Environmental Interpretation Research Project formerly maintained by the Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, in cooperation with the College of Forest Resources, University of Washington. Gregory W. Lovelady was a graduate student in the College of Forest Resources, University of Washington. Harlan Falkin was the 1973 Summer Special Project Manager, Pacific Science Center, Seattle, Washington.

Currently, Wagar is leader of the Recreation Research Project maintained by the Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, in cooperation with the State University of New York College of Environmental Science and Forestry, Syracuse, New York. Lovelady is Recreation Planner, Washington State Inter-Agency Council on Outdoor Recreation, Tumwater, Washington. Falkin is Assistant Manager, Education Department, Pacific Science Center, Seattle.

EVALUATION TECHNIQUES FOR INTERPRETATION: STUDY RESULTS FROM AN EXHIBITION ON ENERGY

Reference Abstract

Wagar, Alan J., Gregory W. Lovelady, and Harlan Falkin.
1976. Evaluation techniques for interpretation: Study results from an exhibition on energy. USDA For. Serv. Res. Pap. PNW-211, 13 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Six techniques for evaluating presentations were studied during an exhibition on man and energy at the Pacific Science Center, Seattle, Wash. A panel of outsiders, suggestion boxes, observed audience attention, and time-lapse photography all proved to be good techniques for evaluating effectiveness.

KEYWORDS: Recreation, information and education, interpretation, environmental education.

RESEARCH SUMMARY
Research Paper PNW-211
1976

The Pacific Science Center's 1973 summer exhibition, "Energy and Its Relation to Man and the Environment," was studied to determine the effectiveness of evaluation techniques. The six techniques tested are rated in table 2.

When a presentation is being developed, problems are frequently obvious and the speed of evaluation is generally more important than its precision; otherwise, personal involvement may become so great that change is resisted. Evaluation before completion should be routine so problems can be corrected before investments in time, energy, and money become large.

With some understanding of the biases inherent in nonrepresentative samples of visitors, interpreters should be able to use inexpensively collected information to increase the effectiveness of presentations.

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Introduction

In visitor centers and other settings for interpretation, evaluation of effectiveness has been widely recognized as important but seldom accomplished. Specific evaluation criteria and methods have not been readily available, and many staffs are too burdened with other duties to work out evaluation procedures. In addition, the high costs of many displays, exhibits, and other unmanned presentations often make experimentation impractical.

A unique opportunity for evaluation arose in 1973 when the staff of the Pacific Science Center created a "summer special" exhibition on energy and then modified it on the basis of evaluation by the Environmental Interpretation Research Project of the Pacific Northwest Forest and Range Experiment Station.

The Pacific Science Center and the Energy Special

Built as the Science Pavilion of the Seattle World's Fair, the Pacific Science Center comprises four buildings and is dedicated to helping the public understand science. In addition to its permanent exhibits on space technology, astronomy, mathematics, and the physical and life sciences, the center has for several years offered "summer specials." These add a dynamic element to the Center's normal attractions, creating topical additions that encourage visitors to return.

The theme for the 1973 summer special was "Energy and Its Relation to Man and the Environment." This "Energy Special" was set up in the Center's Allen Building with the floor space of approximately 80 by 104 feet (24 by 31 meters) divided into five parts. Four parts were used for the presentations listed in table 1. The fifth was used as a reading area.

Nearly all visitors to the Energy Special paid admissions of $1.50 per adult and $0.50 per child under 16. This undoubtedly affected audience composition.

Procedures

Evaluation began only after the Energy Special was complete enough to open--a month and a half after construction began. The first evaluation data were collected from an invited audience on June 28, 3 days ahead of the public opening. Evaluation data were collected until the exhibition closed on September 1, 1973.

In all, nine analyses were made. Six were evaluations: evaluation by a panel of outsiders, volunteered comments, observed audience attention, time-lapse photography, visitor voting at individual presentations, and following sample visitors. The other three examined hours of attendance, visitor characteristics, and interest in possible themes for future summer specials.

PANEL OF OUTSIDERS

During the summer, six "outsiders" were invited to visit the Energy Special and then to be interviewed concerning what they observed. None of the six was a specialist in interpretation, and none was associated with the Pacific Science Center. However, all were professional people with some experience or personal interest in interpreting scientific topics to the public.

VOLUNTEERED COMMENTS

A suggestion box was installed in the reading area with a note pad and pencil and a sign reading "We appreciate your comments. Please leave us a note." To avoid comments on other parts of the Pacific Science Center, the words "Limit comments to Energy Special" were later added.

Table 1--Description and availability of presentations at Pacific Science Center's 1973 summer special on energy and its relation to man and the environment

Trial exhibit area	Formal exhibit area	Informal exhibit area	Laboratory area
Five tables, usually with 1 or 2 employees available to operate exhibits and answer questions.	Minitheater for formal demonstration with informal seating for 20 people.	Puppet theater with seating on carpet and cushions, plus visitor-operated exhibits.	Enclosed classroom with tables, chairs, overhead projector, etc. Loudspeakers and windows permitted others to observe and listen.
Alternate energy sources--Pressing a button by energy source name lighted panel showing trade-off (e.g., generating X kilowatts kills Y fish). (August 27 to September 1)	What's a watt?--Exhibit using bicycle and handcrank generators showed that a kilowatt is great compared with energy a person can produce. (July 1 to September 1)	Kaleidoscope--Visitor stepping into triangular enclosure of mirrors saw his image reflected an infinite number of times. Sign asked, "Are there too many of you?" (July 1 to September 1)	Candy ecology--Participants assumed roles of plants, grazers, and carnivores. Energy flow was simulated by flow of candy among participants. (July 10 to September 1)
Energy storage--Visitors controlled flow from three plastic box "reservoirs" to simulate electric generation for imaginary city. (July 1 to September 1)	Chef Boy O Boy--The "chef" in this demonstration told people they "burn" food for energy. Much fossil energy is used for production, processing, and distribution of food. (July 1 to September 1)	Walt Wasteful--10-minute puppet show on conserving energy in home. Postcards were given to children to mail in ideas on energy saving. Returned cards were displayed near theater. (July 25 to September 1)	Card game--Object was to match "energy source" cards with "positive effect" cards while discarding "negative effect" cards. (July 15 to September 1)
Three dams--Similar to above. Visitors manipulated valves to make water wheel meet changing demand for electricity. (July 1 to July 28)	Gasoline shortage--Reasons were given in slide lecture, with shortage forecast and daily gasoline availability information on map of United States. (August 15 to September 1)	Hot Rod Harry--10-minute puppet show on origin, use, and pollution problems of petroleum. (July 1 to July 25)	Growth patterns--Game with tiles on checkerboard showed that population growth varies with different constraints. (July 1 to July 25)
Fuel hunt--Approximately 50 colored balloons in a box represented the major energy sources. The number of balloons of each color indicated the worldwide abundance of each source. Children were asked to find one balloon of each color. (August 10 to September 1)		Pulleys--Three pulley arrangements showed that a large force over a short distance or a smaller force over a longer distance can represent identical amounts of energy. (July 1 to August 15)	Nuclear radiation--Participants used radioactive materials and Geiger counters to explore effectiveness of shielding. Discussion followed on protection of environment near nuclear powerplants. (July 1 to August 1)
Energy supply puzzle--Each piece represented an energy source, with size of piece proportional to source's importance in energy production. (August 6 to September 1)		Energy waves--Water surface, soap bubbles, and vibrating cords were used to demonstrate transmission of energy by waves. (July 1 to July 28)	
Trade-offs--Horizontal clear plastic tube containing a ball and with variable speed fan at each end. Change in one factor (fan) upsets equilibrium (moves ball) unless balanced by other. (July 1 to September 1)			
Bicycle generator--Connected to 10 light bulbs. Adding bulbs to circuit increased effort needed by person pedaling to maintain brightness. (August 9 to September 1)			
Energy consumption adding machine--Adding machine and energy consumption chart permitted visitors to sum their annual energy use. (August 9 to September 1)			
Solar cooker--With photographs of its use. (July 17 to 23 and July 28 to September 1)			
Issues--Six light bulbs wired so that twisting one would light two, twisting another would dim others, etc. Text explained that side effects of any action are difficult to predict. (July 1 to September 1)			

Comments received during visitor voting (discussed under "Visitor Voting") were combined with comments from the suggestion box and grouped into those received between June 28 and July 16 and those received between July 19 and August 15.

OBSERVED AUDIENCE ATTENTION

Because presentations must hold attention if visitors are to enjoy and learn from them, audience attention was observed at the puppet theater and the laboratory area.[1/]

Two observers were located where they could unobtrusively observe the eyes of audience members. At 2-minute intervals, they scanned the audience and recorded the number of people watching the speaker or what he was presenting. Data were converted into percentages of people present and then graphed.

TIME-LAPSE PHOTOGRAPHY

To avoid some of the limitations of directly observing visitors, time-lapse movies were taken during a 4-day test. These used a super-8 movie camera with zoom lens and "single framing" capability. Colored film (ASA speed 160) was used without supplemental lighting. The camera was triggered by a cable release connected to a solenoid activated by microswitches and cams on an inexpensive electric clock motor. When gear ratios were altered exposures could be obtained at intervals of 4, 5.5, 8, 16, or 32 seconds. The entire assembly was mounted approximately 10 feet above the floor and 50 feet from the area photographed.

VISITOR VOTING

To permit visitors to vote directly on individual presentations, voting boxes and packets were provided from June 28 through July 17 and again from August 21 through August 31.

At each of six presentations, a box with five slotted compartments was provided, permitting visitors to vote from 1 (poor) to 5 (good) on each presentation. A colored photograph on each box showed the presentation to which it applied. As the Energy Special evolved, some boxes were shifted to sample newly completed presentations.

Each voting packet included a card with six voting slips attached--one for each presentation. A number on each card and its attached slips made it possible to determine how many votes each visitor cast.

At randomly selected times each day during the two sample periods, voting packets were given to as many visitors as possible--with two constraints. First, packets were given only to visitors judged to be 12 or older and capable of understanding instructions; second, no visitor received a packet without a complete explanation of its use.

Although each visitor received only one voting packet, three different packets were used, each with a different question. Each visitor was therefore asked only one of the questions: "How effectively was the information presented?" "How enjoyable did you find the subject matter?" and "How much new information did you gain?" To aid tabulation of answers, slips of a different color were used for each question.

Slips were collected daily and sorted by question (indicated by color of slip) and slot (1 to 5). The "average" vote was then computed (on a scale of 1 to 5) for each question at each presentation.

[1/] Dick, Ronald E., Erik Myklestad, and J. Alan Wagar. 1975. Audience attention as a basis for evaluating interpretive presentations. USDA For. Serv. Res. Pap. PNW-198, 7 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

FOLLOWING SAMPLE VISITORS

Between July 24 and August 17, 171 randomly selected visitors were followed unobtrusively through the Energy Special. The observer carried recording forms and two stopwatches--one to record the visitor's total time in the building, the other to record his time at each exhibit or demonstration.

Because most presentations required at least some time for understanding, a "minimum learning time" was defined for each, based on the judgment of demonstration personnel and managers familiar with both visitor behavior and the intended message or objective of each presentation. Contact with a presentation was recorded only when a visitor stopped there for at least the minimum learning time.

As a basis for ranking frequencies of exposure, a contact factor was computed for each presentation as follows:

$$\text{Contact factor} = \frac{\text{number of contacts observed}}{\text{number of days presentation sampled}}.$$

HOURS OF ATTENDANCE

Soon after the Energy Special opened, it became obvious that the work schedules of demonstration personnel needed better coordination with peak hours of visitation. An attendance survey was therefore made by a volunteer working from 11 a.m. (when the Center opened) until 5 p.m. on 10 randomly selected days between July 20 and August 2. Although the center remained open until 8 p.m., few visitors arrived after 5 p.m. This permitted identification of peak periods.

Visitation data for the entire Pacific Science Center were routinely taken at the Center's ticket booth, so the survey also showed the percentage of visitors reaching the Energy Special.

VISITOR CHARACTERISTICS

To determine who visits the Pacific Science Center, a brief questionnaire was given to one member of each group entering the Center between August 3 and August 17. The 824 questionnaires distributed represented 2,615 visitors. All questionnaires were completed on the spot and dropped into a slotted box. Questions asked for a breakdown of each group by age classes and sex, the place of residence for each member in the group, and the number of times the person completing the questionnaire had visited the Pacific Science Center.

FUTURE "SPECIALS" QUESTIONNAIRE

To examine visitor interest in selected themes for future summer specials, a brief questionnaire was used for approximately a week in late August. This was provided in a rack attached to the visitor suggestion box in the reading area. Visitors could choose among four alternatives or write in their own. The four alternatives were: (1) man's five senses, (2) computers, (3) expansion of the Energy Special, and (4) man's effect on the environment.

Results and Discussion

A key finding of this study is the importance of feedback *early* in the development of a presentation before creative people have invested great amounts of time, energy, and ego. During the early stages of development, promptness of feedback and ease of obtaining it are probably more important than its precision.

The importance of timely feedback became obvious during the Energy Special. The staff of the Pacific Science Center actively sought and welcomed feedback as a basis for changing and improving the

presentations. However, evaluation did not begin until the exhibition was ready to open. This made any substantial changes quite painful for individuals who had labored under pressure for over a month to give physical form to their plans and ideas. Also, it took time to develop replacements for presentations to be discontinued. As a result, some ineffective presentations were retained longer than desirable.

The evaluation techniques tested are rated in table 2 and discussed below in terms of speed, burden on personnel, other costs, and usefulness.

Table 2--Rating of six techniques for evaluating interpretive presentations

Technique	Speed of feedback	Burden on personnel	Cost for equipment and materials	Guarantee against bias	Usefulness and limitations
Opinion from panel of selected outsiders	Excellent	Small	Low	Low	Identifies major problems before public presentation
Volunteered comments (via suggestion box)	Good	Small	Low	Low	Can identify range of reactions; respondents self-selected
Observed audience attention	Good	Moderate	Low	Good	Requires training. Assumes that "attention" indicates effectiveness. Respondent characteristics may differ at different presentations, making comparisons risky
Time-lapse photography	Good	Small	Moderate to high	Good	Records continually, identifies use patterns, and captures infrequent occurrences with little burden on personnel. Area covered from one camera position usually quite limited
Visitor voting at individual presentations	Fair	Moderate to great	Moderate	Moderate	Respondent characteristics may differ at different presentations, making comparisons risky
Following sample visitors	Good to fair	Great	Low	Good	Best for studying visitor orientation and movements. Inefficient for rating visitor interest in specific presentations

PANEL OF OUTSIDERS

One of the fastest ways to evaluate a presentation is to have several thoughtful outsiders examine it and comment on its strengths, it shortcomings, and opportunities for improvement. Such evaluation does not depend on public reaction and can therefore be used before a presentation is nearing its final form.

Because outside opinion is only as good as the insights of the outsiders used, careful thought should be given to their selection and preparation. Experienced interpreters and designers may bring preconceptions as well as special insights to the task. Thus, specialists whose views may closely parallel those of the people who created a presentation may give a less accurate estimate of public reaction than that provided by intelligent people who are not closely associated with interpretation and have no specialized knowledge of the subject matter being presented. To focus the attention of outsiders on pertinent matters, a checklist such as that suggested in figure 1 can be used.

VOLUNTEERED COMMENTS

Collection of volunteered comments can start as soon as a presentation is offered to the public. Such comments are easily obtained by providing a sign and suggestion box. They offer an evaluation opportunity too often neglected. Because suggestion boxes assure anonymity and prevent visitors from seeing other comments, they should yield better information than a visitor register with a "comments" column.

CHECKLIST

1. OBJECTIVES:
   a. From your observation of the interpretation, what do its objectives seem to be?
   b. Are they reasonable?
   c. (LATER) Are these the objectives outlined by the creators of the interpretation?
   d. If not, why the discrepancy?

2. AUDIENCE:
   a. In this setting, what are the likely objectives of the audience, and are the objectives of the interpretation compatible with the objectives of the audience or potential audience?
   b. What proportion of the potential audience is stopping?
   c. How long would it take the average visitor to fully experience this interpretation?
   d. How long are visitors actually spending with this interpretation?
   e. Do visitors seem interested or uninterested? Why?
   f. Which age groups seem interested and which uninterested?

3. SETTING AND DESIGN:
   a. Is it easy for visitors to reach or find this interpretation?
   b. Is the visitor given sufficient clues to experience different elements or units of the interpretation in a meaningful sequence?
   c. Is it easy and comfortable for the visitor to experience this interpretation? (Seating, if appropriate; suitable viewing available to children; etc.)

4. CONTENT AND DESIGN:
   a. Is any of the information incorrect? Unclear? Inappropriate?
   b. Do any conflicts occur within this interpretation or with nearby interpretation? (Consider competition for attention as well as conflicts in subject matter.)
   c. What opportunities for improvement are available?
   d. Why or how would these work better?

Figure 1.--Checklist for judging interpretive presentations.

Volunteered comments do not give unbiased estimates of average opinion and may overrepresent highly motivated or irritated visitors. However, because different visitors respond quite differently to any one presentation, interpreters must consider the *range* and distribution of opinion rather than average opinion.

Volunteered comments tend to focus on whatever strikes visitors as especially good or bad, thus detecting the extremes that define the range of opinion. If the conditions under which comments are collected do not change, volunteered comments can also identify trends.[2/]

[2/] If such conditions as the location of a comment box are changed, what appears to be a shift in visitor opinion might well result from the fact that comment boxes in different locations sample populations with somewhat different compositions. Likewise, if different kinds of visitors frequent a facility at different times of year, a change thought to result from improvements in the facility might in actuality result because an increased proportion of the visitors had strong interest in the things presented.

Table 3--*Summary of visitor comments on exhibits at the Pacific Science Center's summer special on energy, 1973*

Visitor comments	June 28 to July 16		July 19 to August 15	
	Number	Percent	Number	Percent
Complimentary	140	54.5	157	75.8
Suggested additions or improvements	38	14.8	18	8.7
Information poorly communicated	22	8.6	10	4.8
Boring	9	3.5	8	3.9
Expand and improve	10	3.9	7	3.4
Too elementary	9	3.5	5	2.4
Need more demonstrators	24	9.3	2	1.0
Demonstrators lack knowledge	5	1.9	0	0
Total	257	100.0	207	100.0

Table 3 summarizes visitor comments volunteered during two periods. Of the 464 comments received, well over half were complimentary, which, by itself, means little. A "congeniality bias" results from people's widespread tendency to be agreeable. The shift from 54.5-percent to 75.8-percent complimentary remarks is not readily explained by shifts in visitor composition or changed procedures for eliciting comments. This parallels other evidence of substantial improvement during the Energy Special.

Although compliments are nice, specific comments and suggestions are more likely to be genuine and provide a more useful basis for improvement. Some comments focused on lack of demonstration personnel, limitations in their knowledge, and level and effectiveness of communication. The same problems were identified by other evaluation techniques and were largely corrected part way through the summer, as reflected in the July 19 to August 15 columns of table 3.

OBSERVED AUDIENCE ATTENTION

Observation records can quickly identify changes in audience attention within a presentation (fig. 2) as well

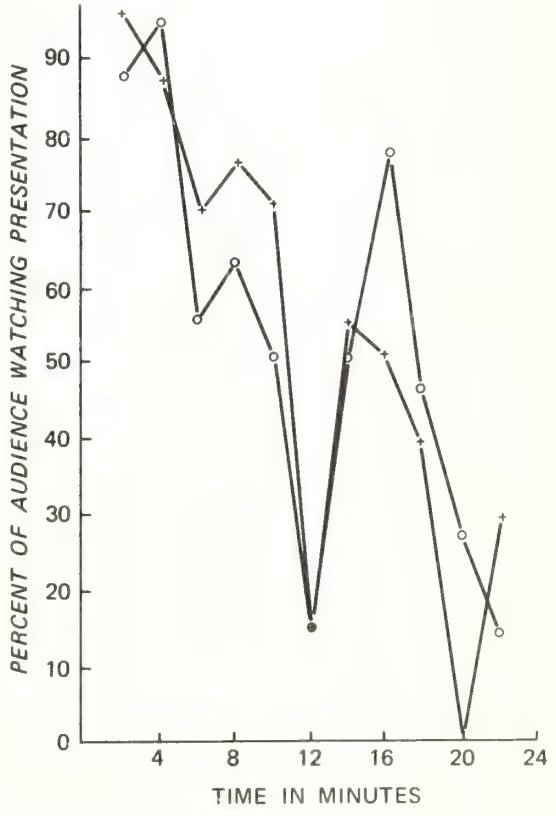

Figure 2.--Observed attention to the "candy ecology" laboratory presentation, Pacific Science Center, Seattle, Washington, 1973. Energy flows among plants, grazers, and carnivores were simulated by exchanges of candy among participating visitors.
+ = Observer 1. o = Observer 2.

as differences between presentations. Investing a little time in training observers pays off in more reliable results. As shown in figure 2, two trained observers consistently recorded similar patterns of attention.

Used with an observer's remarks, a tape recording of a presentation permits reasons for fluctuations in attention to be studied.

TIME-LAPSE PHOTOGRAPHY

Time-lapse photography quickly identified important patterns of visitor use during the Energy Special. For example, a time-lapse sequence showed the adding machine at the "family energy consumption" exhibit to be in almost constant use. It also showed that the demonstration personnel on duty in the trial exhibit area were often either absent or too busy to interact with all visitors. (Volunteered comments also identified the unavailability of demonstration personnel, table 3.)

For approximately $180 each, completely self-contained super-8 "surveillance cameras" are now commercially available. These time-lapse systems can be set up to record at intervals ranging from 1-1/4 to 90 seconds.

The 4-day test of time-lapse photography provided several insights for planning future time-lapse work. The preferred interval between exposures became 4 seconds. With intervals of 8 or more seconds, it was difficult to visualize the continuity of visitor movements while reviewing the film. At 4-second intervals, a 50-foot super-8 film magazine lasted 4 hours. The high-speed color film (ASA 160) did not require supplemental lighting; and "overnight" processing service was available for this film in Seattle. The lens was used at its shortest focal length (8 mm) during the entire test. A zoom lens was not necessary. Review of the film would have been facilitated with a projector equipped to run at two to four frames per second and to stop on selected frames. (Such projection equipment may cost from $300 to $700. But a good film editor is nearly as satisfactory.)

Time-lapse photography has four advantages: (1) It records continuously with little burden on personnel. (2) It creates a permanent record that can be studied and used in training. (3) By "compressing" time, it captures patterns of use that are otherwise difficult to visualize. (4) It makes a great amount of information readily accessible to top managers by condensing it to a few minutes of viewing.

VISITOR VOTING

The voting procedure identified general improvement in presentations during the summer but had several weaknesses. Although more than half the people who received voting packets voted at least once, only one person in seven voted on all six presentations. Visitors (as well as the panel of outsider found voting burdensome. Because tearing a slip from a card and dropping it in a multislotted box seemed simple, difficulti and discomfort with the voting system were quite unexpected. Problems may have resulted from a combination of (1) having to carry a voting packet, (2) being asked to concentrate on and respond to only one abstract dimension of a presentation, and (3) being expected to see the exhibition more thoroughly than planned. Visitors seemed generally unable or unwilling to partition their overall impressions in the abstract way requested by the questions. (Each visitor received a single "question card" designed to focus his evaluation on the enjoyability of the subject matter, how effectively it was presented, or the amount of new information gained.) If used, voting probably should be limited to total reactions to a single presentation.

An exhibit's location also seemed to influence its rating, with the highest ratings given to the last exhibits

encountered on the route usually taken by visitors. The most highly motivated (and therefore most enthusiastic) visitors probably saw and voted at more presentations than the average visitor. In contrast, the visitor only mildly interested in the whole exhibition was likely to leave after seeing and voting on the first one or two presentations encountered. Thus, much of the vote for some presentations may have come primarily from the more enthusiastic visitors. Bias from this source is inherent in the voting procedures and would be difficult to avoid.

As a final weakness, sorting and counting the voting slips required a great amount of time, preventing prompt feedback to those creating and modifying the exhibition.

FOLLOWING SAMPLE VISITORS

Although direct observation of visitor movements showed a great deal about the ways people move through a visitor center, it was not an efficient way to evaluate specific presentations. Approximately 72 man-hours were required (4 hours per day for 18 days) to collect data on 171 visitors making 206 contacts with the presentations offered. The relatively few encounters recorded for each presentation nevertheless showed a tremendous variation in the ability of different presentations to hold visitors for long enough to have meaningful effects (table 4).

On the average, unmanned presentations that were always available to visitors had higher contact factors than personal but unscheduled presentations. Demonstration personnel were not always available. Also, many visitors seemed to consciously avoid interacting with demonstrators.

Scheduled presentations had contact factors ranging from very good to very bad. The 5-minute Chef Boy O Boy presentation was scheduled

Table 4--

Exhibit	Period available	Minimum learning time	Number of visitor contacts and days sampled	Visitor contact factor
		Minutes		
Kaleidoscope[1/]	7/1 to 9/1	0	42/18	2.33
Chef Boy O Boy[2/]	7/1 to 9/1	3	30/18	1.67
Solar cooker[1/]	7/17-23, 7/28 to 9/1	[illegible]	24/15	1.60
Reading area[1/]	7/1 to 9/1	0.5	26/18	1.44
Gasoline shortage (slides)[2/]	8/15 to 9/1	1	3/3	1.00
Walt Wasteful (puppets)[2/]	7/25 to 9/1	3	17/18	.94
Adding machine[1/]	8/9 to 9/1	[illegible]	6/7	.86
Candy Ecology Lab.[2/]	7/10 to 9/1	7	14/18	.78
Energy storage[3/]	7/1 to 9/1	0.5	13/18	.72
Issues[3/]	7/1 to 9/1	[illegible]	8/18	.44
Ballot[1/]	7/1 to 8/15	1	8/18	.44
Puzzle[3/]	8/6 to 9/1	0.5	3/8	.38
What's a Watt[2/]	7/1 to 9/1	3	6/18	.33
Trade-offs[3/]	7/1 to 9/1	1	5/18	.28
Nuclear Radiation Lab.[2/]	7/1 to 8/1	3	1/18	.06
Fuel hunt (balloons)[3/]	8/10 to 9/1	[illegible]	0/6	.00
Card game[2/]	7/15 to 9/1	[illegible]	0/18	.00
		Σ = 31.5		

1/ Independent of demonstrators and always available for visitor use.

2/ Performed on a scheduled basis. Usually available the following number of times each day: Chef Boy O Boy, 3; Gasoline shortage, 1; Walt Wasteful, 4; Candy Ecology Lab., 4; What's a Watt, 2; Nuclear Radiation Lab., 2; Card game, 1.

3/ Dependent on demonstrators; demonstrator assigned continuously.

to reach visitors during peak hours and required no active participation by audience members. Because the minitheater had no walls around the seating area, people could drift in or out unobtrusively. In contrast, presentations in the laboratory area tended to be longer (up to 30 minutes for the Candy Ecology presentation), required active audience participation, and were enclosed in a room that inhibited unobtrusive entry or exit. Also, the room had windows and speakers, permitting visitors outside the room to follow any activities taking place inside. In the predominantly "walk-through" setting, people seemed reluctant to commit themselves to anything they could not readily leave. Also, adults tend to be nervous about participating in anything that might make them look foolish to others.

Ratios between potential, possible, and actual amounts of contact are interesting. During the 18 days on which visitor movements were observed, an average of 15 presentations was available.[3/] Thus, the maximum number of contacts that could conceivably have been recorded was 2,565 (15 presentations X 171 visitors). However, the unavailability of demonstration personnel and the "short circuit" routes taken by many visitors reduced the total number of contacts actually possible to less than a fifth of this (503). Only 206 contacts were actually made by the 171 visitors observed.

On the average, the observed visitors stayed in the Energy Special area a short time. However, the average time increased from approximately 7 minutes during the first 18 days of observation to 17 minutes during the last 7, reflecting improvements in the exhibition. The 17-minute average stay compares favorably with the postulated minimum learning time of 31.5 minutes for all presentations, including those unavailable at any given moment.

VISITOR CHARACTERISTICS

Results from the survey of visitor characteristics showed that over half the visitors sampled were visiting the Pacific Science Center for the first time and lived outside the State of Washington. Over 60 percent were 25 or younger, and the most common group size was two persons. Although only the period August 3 to August 17 was sampled, results probably are close to what would have been found by sampling the entire July 1 to September period during which the Energy Special was available. Fewer out-of-State visitors and families with school-age children may visit the Pacific Science Center during June and late August.

HOURS OF ATTENDANCE

Approximately 55 percent of the people entering the Pacific Science Center eventually arrived at the Energy Special (fig. 3). To reach it, they normally

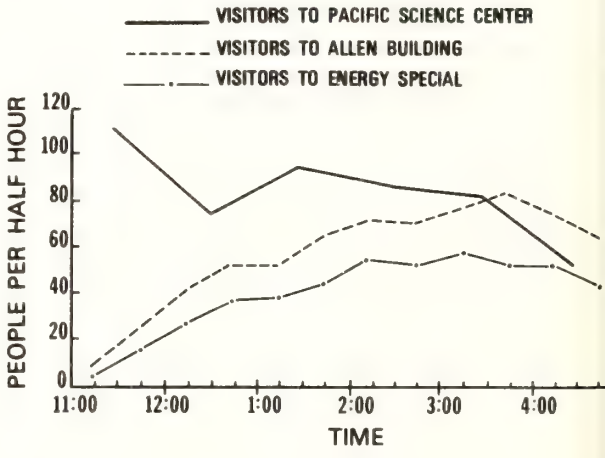

Figure 3.--Average attendance per half ho at Pacific Science Center, Allen Buildi and "Energy Special," July 20 to August 1973. (Although visitation to Pacific Science Center was recorded on an hourl basis, data have been adjusted to a hal hourly basis to make them comparable wi data for Allen Building and Energy Spec

3/ Actually, several more exhibits were available for a few days, but presentations available for less than 4 days were not included.

traversed three other exhibit halls with floor space equivalent to about two football fields! Traffic through the Energy Special therefore reached its higher levels approximately 45 minutes following the "after lunch" peak in admissions to the entire Center.

In addition to general fatigue, lack of a clear traffic pattern may explain why more Pacific Science Center visitors did not attend the Energy Special. At the main entrance to the Energy Special, the most prominent sign pointed to the Balcony Book and Gift Shop, and a one-way door prevented visitors from backtracking directly to the Energy Special once they had entered the gift shop. Also, visitors were provided few clues to an efficient route into and through the Energy Special. Clarification of this route and addition of one or two attention-getting exhibits near the most commonly used entrance to the Energy Special might have increased attendance.

FUTURE "SPECIALS" QUESTIONNAIRE

Of the questionnaires distributed on future "specials," 245 were returned. Among the four suggested topics, "computers" was the most popular with 98 responses (40 percent), followed by "man's effect on the environment" with 62 responses (25 percent), "man's five senses" with 43 responses (18 percent), and "expansion of the Energy Special" with 22 responses (9 percent). There were 20 write-in responses (8 percent) covering such diverse topics as electronic music, sex, undersea exploration, insanity and witchcraft, and the population explosion. Responses came only from people who chose to complete the short questionnaire, and highly motivated visitors may have been overrepresented.

When people's preferences were separated by age groups, a "mirror image" contrast emerged between "computers" and "man's effect on the environment" (fig. 4). This parallels other findings that, between childhood and maturity, people's interest tend to shift from the concrete and discrete toward the abstract and integrated and from concern with individual things toward processes and social concerns. Computers are sensational machines with awesome power, associated in many people's minds with physical images of spinning tape reels and flashing lights. In addition, computers are means rather than ends. In contrast, "man's effect on the environment" is much more abstract, involving social concerns and goals and the integration of diverse processes and factors.

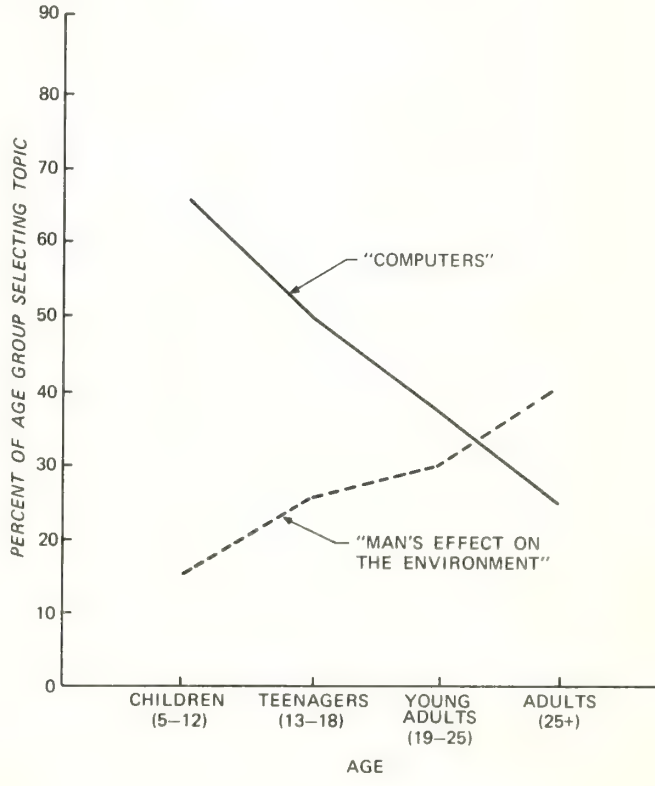

Figure 4.--Effect of age on preferred themes for future "summer specials" at the Pacific Science Center.

Although the data of figure 4 come only from "self-selected" visitors, they nevertheless warn that presentations aimed at one age group may largely miss another.

Conclusions

Two groups of conclusions result from evaluation of the Pacific Science Center's "summer special" exhibition, "Energy and Its Relation to Man and the Environment." One of these concerns evaluation techniques; the other, the "Energy Special" itself.

GUIDELINES FOR EVALUATION

From experience gained with six evaluation techniques, 12 guidelines for evaluation are offered:

1. When an interpretive presentation is being developed, the speed of evaluation is generally more important than its precision.

2. Comments from a few thoughtful outsiders can identify major problems at an early stage before large investments of time, money, and personal involvement make changes awkward. Pretesting could often avoid costly errors and should be routine for most presentations.

3. Documentation is important, becoming more than mere opinion to be countered by the opinion of anyone reluctant to change. Graphs, tables, and other summaries can separate widely shared reactions from those of isolated "cranks" and can uncover specific misunderstandings and problems.

4. Evaluation need not be complicated or expensive.

5. Once a presentation is open to the public, suggestion boxes will elicit many useful comments. Although such volunteered comments usually include many gratuitous compliments and define no "unbiased average," they do identify the range of visitor reactions as well as specific problems or opportunities for improvement.

6. When collected in a consistent manner, volunteered comments obtained at different times can identify trends in effectiveness.

7. Time-lapse photography and direct observation of audience attention can identify major difficulties in a presentation rather quickly and at reasonable costs in manpower and money.

8. Following randomly selected visitors can provide useful insights into the ways visitors perceive and find their way among the components of a presentation. However, the technique is time consuming and, in focusing on one visitor at a time, is not an efficient way to examine use levels or patterns at specific points within a building or exhibit room.

9. Because different people will respond to presentations quite differently, responses in some cases need to be classified by the age, sex, and perhaps other observable characteristics of visitors.

10. Direct comparisons of visitor response to different exhibits or presentations may be misleading. Because of inadequate orientation as well as differences in time and motivation, the kinds of visitors predominating at different presentations may differ markedly.

11. Visitors should not be expected to undertake complex or lengthy evaluation tasks. Because visiting interpretive presentations is usually a leisure time activity, carrying evaluation forms or reading even slightly complex instructions may be perceived as a substantial burden.

12. Requests that people respond to only one abstract dimension of a presentation are not likely to be understood.

THE ENERGY SPECIAL

Three different measures indicated improvement during the Energy Special. Favorable comments in the suggestion box, favorable "votes," and average length of stay all increased. Presentations probably would have improved in any case as a result of increased experience among personnel, informal feedback, and guidance from supervisors. However, formal evaluation accelerated improvement by diagnosing and documenting specific problems. These

included a mismatch between peak hours of visitation and the availability of demonstration personnel, the distraction a visitor-operated exhibit caused for a nearby presentation, and presentations that generated little visitor interest.

Evaluation identified three additional difficulties:

1. Having personnel available to answer questions and discuss exhibits was not very efficient, yielding few visitor contacts for the manpower expended. Similar results are likely whenever the flow of visitors is highly uneven--at times overtaxing the ability of personnel to interact with interested visitors, at other times leaving such personnel nearly idle.

2. Visitation to and enthusiasm at the Energy Special might have been substantially greater if it had been easier to reach. Of all visitors to the Pacific Science Center, 55 percent did reach the Energy Special, but usually after passing through three other buildings of exhibits.

In addition, eye-catching exhibits near the entrance to the Energy Special might have captured the interest of more visitors, a parallel to the "western" writer's recommendation, "Shoot the sheriff on page 1."

3. The enclosed "laboratory area" provided substantially fewer visitor contacts than the "minitheater," where visitors could drift in or out. Many visitors, especially adults, tend to avoid "classroom" settings where escape is difficult, participation is required, and ignorance may be exposed. However, people who did visit the laboratory area rated it quite highly.

Evaluation of interpretive presentations probably will continue to be more art than science. A great amount of somewhat imprecise information can be obtained at little cost in time and money and with little burden on visitors. With some understanding of the sources of bias and with overlapping data collection procedures as a check on any one method, managers of interpretive programs should be able to avoid the major pitfalls of using data from non-representative samples of their visitors. Many problems can be diagnosed from quite limited information. Nevertheless, managers must still weigh the risks of somewhat biased information against the costs of increased precision.

* * * * * *

Wagar, Alan J., Gregory W. Lovelady, and Harlan Falkin. 1976. Evaluation techniques for interpretation: Study results from an exhibition on energy. USDA For. Serv. Res. Pap. PNW-211, 13 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Six techniques for evaluating presentations were studied during an exhibition on man and energy at the Pacific Science Center, Seattle, Wash. A panel of outsiders, suggestion boxes, observed audience attention, and time-lapse photography all proved to be good techniques for evaluating effectiveness.

KEYWORDS: Recreation, information and education, interpretation, environmental education.

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P.O. Box 3141
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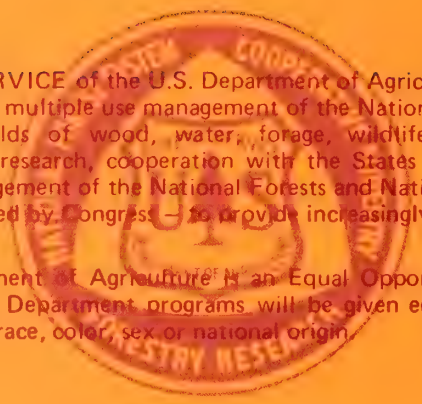

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USDA Forest Service Research Paper PNW-212
1976

RICE IMPACTS
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f Log Export Restrictions
nder Alternative Assumptions

Richard W. Haynes

Pacific Northwest Forest and Range Experiment Station
Forest Service U. S. Department of Agriculture
Portland, Oregon

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Price Impacts of Log Export Restrictions Under Alternative Assumptions

Reference Abstract

Haynes, Richard W.
1976. Price impacts of log export restrictions under alternative assumptions. USDA For. Serv. Res. Pap. PNW-212, 25 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The impact on softwood lumber and stumpage prices of a hypothetical ban of log exports was computed for alternative assumptions about the market for western softwood lumber. The log export ban was treated as shifting the U.S. supply of western softwood. Various assumptions were made about the direction, extent, and timing of this shift. Other critical assumptions included the values for the U.S. and Canadian supply elasticities and the U.S. demand elasticity. Price changes attributed to log export restrictions were computed for each of the various combinations of assumptions.

KEYWORDS: Supply/demand (forest products), import/export (forest products), trade policy (international).

RESEARCH SUMMARY

Research Paper PNW-212

1976

The price changes attributable to further log export restrictions depend, in part, on the values of various assumptions comprising the structure of the market for western softwood lumber. The significant assumptions are the direction, extent, and timing of the supply shift induced by log export restrictions, the degree of price responsiveness of U.S. and Canadian producers and U.S. consumers, and the relationship between stumpage and lumber prices. In recognition of the uncertainty surrounding the value for each assumption, a range of values for each assumption was used and numerous price changes were simulated.

Following a ban on log exports, western softwood lumber prices would either decrease as much as 16 percent or increase by as much as 17 percent depending on the direction assumed for the supply shift. The equivalent changes in the stumpage market would be 26 and 29 percent, respectively.

The results demonstrate that price impacts of log export restrictions are the greatest in the stumpage market. One implication is that the comparative advantage of west coast lumber in U.S. markets would be changed following log export restrictions. The extent of this change depends on how price changes in the stumpage market affect the cost of producing western softwood lumber. Another implication is the detrimental impact of lower stumpage prices on the economic feasibility of intensive management programs in the Pacific Northwest. In the long run, curtailment of these programs might result in a reduction of available supply leading to higher prices.

The advantage of the model framework is that it organizes several diverse assumptions to support various estimates of price impacts which heretofore had been a matter of conjecture. The model does not alleviate the uncertainty regarding the response of industry to policy changes. But to a large extent, industry response dictates the potential price impacts associated with changes in export policies.

BACKGROUND

Alternative log export policies have been debated on the basis of the impact of export restrictions on U.S. trade and foreign policy, value and employment created from logs in the export market compared with the domestic market, price and availability of timber in the Pacific Northwest, and U.S. forest products prices. An understanding of these issues is necessary to place in perspective the positions of various individuals and groups affected by log exports. This report addresses the issue of the effect of log export restrictions on prices. The potential impacts of trade policies on prices, however, are only part of the basis on which these policies have been considered.

The basis for concern over the price impacts of log export restrictions has centered on the price and availability of timber in the Pacific Northwest and on the price of softwood construction materials in U.S. markets. Individuals and organizations in favor of log exports have argued that higher stumpage prices due to the export market are an incentive for more intensive forest management which increases timber supply and leads to better timber utilization. Those against log exports have argued that higher stumpage prices increase competition for timber in the Pacific Northwest making producers in the region less competitive in domestic markets compared with other U.S. and Canadian producers. Those against log exports have also argued that higher stumpage prices lead to higher lumber prices and ultimately higher cost housing in the United States.

The stumpage and lumber price impacts of further restrictions of softwood log exports originating in west coast States would depend on how producers and consumers in the United States, Canada, and Japan respond to this change in trade policy. Different scenarios can be hypothesized for the type and magnitude of price impacts, depending on the assumptions made about the responses of producers and consumers in each of the countries.

Opponents of further restrictions on softwood log exports argue that restrictions would not guarantee lower stumpage and lumber prices. This argument assumes that lumber exports would not be restricted and that foreign consumers, primarily Japan, would still need construction materials of the type and quality previously manufactured from the softwood logs they formerly imported. Foreign demand for softwood lumber would therefore increase. Some of the lumber processing capacity in the United States and Canada which would have been used to produce lumber for the U.S. market would instead be used to produce lumber for Japanese consumers, especially in tight markets such as existed in 1972-73.

Several years may be necessary to increase lumber processing capacity to supply both the U.S. and foreign markets with lumber at prices which were in effect before the additional restrictions on U.S. softwood log exports. This sequence of events, after further restrictions on U.S. softwood log exports, would tend to reduce rather than increase lumber supply in U.S. markets and tend to increase rather than decrease the prices of softwood lumber in U.S. markets.

Opponents of further restrictions on softwood log exports argue that any price decreases in stumpage markets attributable to the restrictions would tend to be offset by decreased utilization of the timber resource. Less of the lower quality portion of the resource would be processed into lumber. This decrease in timber volume flowing into stumpage and log markets would tend to maintain stumpage prices.

Proponents of further restrictions on softwood log exports argue that current high log and stumpage prices in the Pacific Northwest are both symptoms of past export policies and indicators of the availability of processing capacity to use additional timber volume to be made available through additional restrictions on softwood log exports. In view of projected declines in availability of timber from private lands in the Pacific

Northwest over the next two decades and in view of uncertainties over timber flows from National Forest lands, further restrictions on exports are necessary to insure the economic viability of a major portion of the timber processing industry in the Pacific Northwest.

According to proponents of further restrictions on softwood log exports, lower stumpage prices would increase the competitive position of Pacific Northwest producers in both U.S. and foreign markets. Additional volumes of lumber from coastal British Columbia would probably be exported to Japan rather than the United States, but shipments from the rest of Canada would not be significantly affected. More lumber would be produced in the Pacific Northwest because of the additional restriction on U.S. softwood log exports and in total, U.S. softwood lumber prices would decrease.

The realization of either of these scenarios depends on the net effect of the behavior of producers and consumers after the change in trade policy. In this report, no attempt is made to evaluate either scenario in terms of the likelihood of occurrence. There is too little historical precedent to judge how the market system would respond to further restrictions on softwood log exports.

Even though a likely scenario is difficult to define for market responses to a further restriction of log exports, the price impacts associated with alternative scenarios and the sensitivity of softwood lumber and stumpage prices to various behavior patterns of producers and consumers can be demonstrated. The purpose of this report is to show for different assumptions about the structure of the softwood lumber market, the potential price impacts of a complete ban on U.S. softwood log exports. The market structures which are assumed in the following analysis do not exactly correspond with either scenario of events stated for proponents and opponents of further restrictions of softwood log exports. Despite this possible shortcoming, the analysis should prove useful in the following ways to legislators and others interested in trade policy:

1) The analysis provides an estima of possible price impacts associated with two extreme scenari of events.
2) The analysis demonstrates the sensitivity of price impacts to key variables in the market structure.

The sensitivity analysis approach used in this report will not resolve the debate over the price impacts of export restrictions. The analysis can be used, however, to identify the implied assumptions about market structure variables inherent in opposing views on the magnitude of price impact When used in this way, the analysis should aid in understanding the positions of individuals concerned about export restrictions.

THE CONCEPTUAL FRAMEWORK

The first step in assessing the potential impacts of additional log export restrictions on U.S. softwood lumber prices and Pacific Northwest stumpage prices is to define the structure of the market used in the analysis This structure dictates how lumber and stumpage prices are determined and how a change in log export restrictions works through the market to change prices. Figure 1 illustrates the structure of the U.S. lumber market used in this analysis.

The analysis assumes that the U.S. demand for the type of softwood lumber produced in the Western United States and Canada can be represented by one demand schedule which shows how consumers change their purchases as the price of lumber changes. In figure 1, this schedule is labeled "total U.S. demand" and shows that consumers would purchase less as lumber prices increase

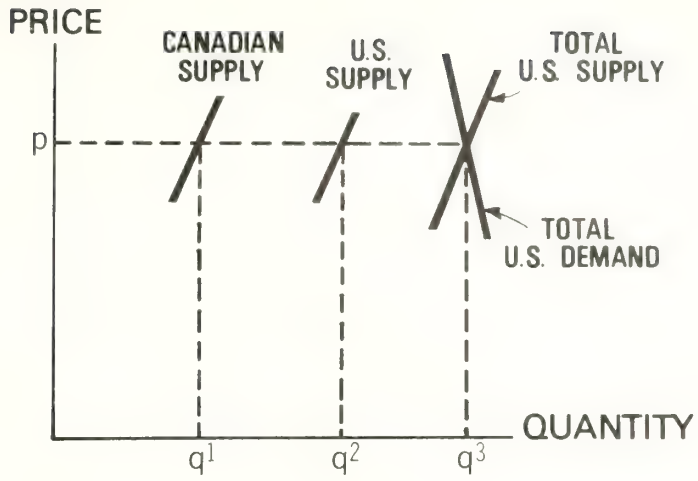

Figure 1.--Assumed model of U.S. market for western softwood lumber.

The analysis treats the U.S. supply of western softwoods as being composed of two components: lumber produced in the Western United States and lumber produced in Canada (largely in British Columbia) destined for the U.S. market. In figure 1 this is represented by U.S. and Canadian supply schedules which are summed together to form a total U.S. supply schedule for western softwoods. These supply schedules show that as the lumber price increases, both U.S. and Canadian producers manufacture more lumber for the market.

Since the quantity supplied increases as price increases and the quantity demanded decreases as price increases, the schedules of total U.S. supply and total U.S. demand intersect to determine the market price and quantity. In figure 1 the total supply and demand schedules intersect to determine the market price (p) and quantity (q^3) of western softwood lumber produced in the Western United States and Canada. The market quantity (q^3) is the sum of the western softwood lumber produced in Canada and shipped to the United States (q^1) and the western softwood lumber produced in the United States (q^2) for domestic consumption.

In the analysis used in this report, no provision is made for price induced changes in foreign demand for softwood lumber nor are any provisions made for possible limits on lumber production due to a lack of processing capacity. In addition, the analysis assumes that any additional timber volume which enters the market after implementation of export restrictions is processed into lumber. No provision is made for the possible diversion of some of this volume to the plywood industry.

These assumptions and the hypothesized structure of the U.S. market for western softwood lumber dictate how further restriction of softwood log exports might influence U.S. prices for western softwood lumber. For example assume that a log export restriction induces greater U.S. production of western softwood lumber. In terms of this analysis, the chain of events following an increase in production is summarized in figure 2. The U.S. supply curve shifts outward (to the right). The Canadian supply schedule is not shifted by the change in U.S. supply nor is the total U.S. demand for western softwood lumber. Because total U.S. supply is defined as the sum of Canadian and U.S. production, total U.S.

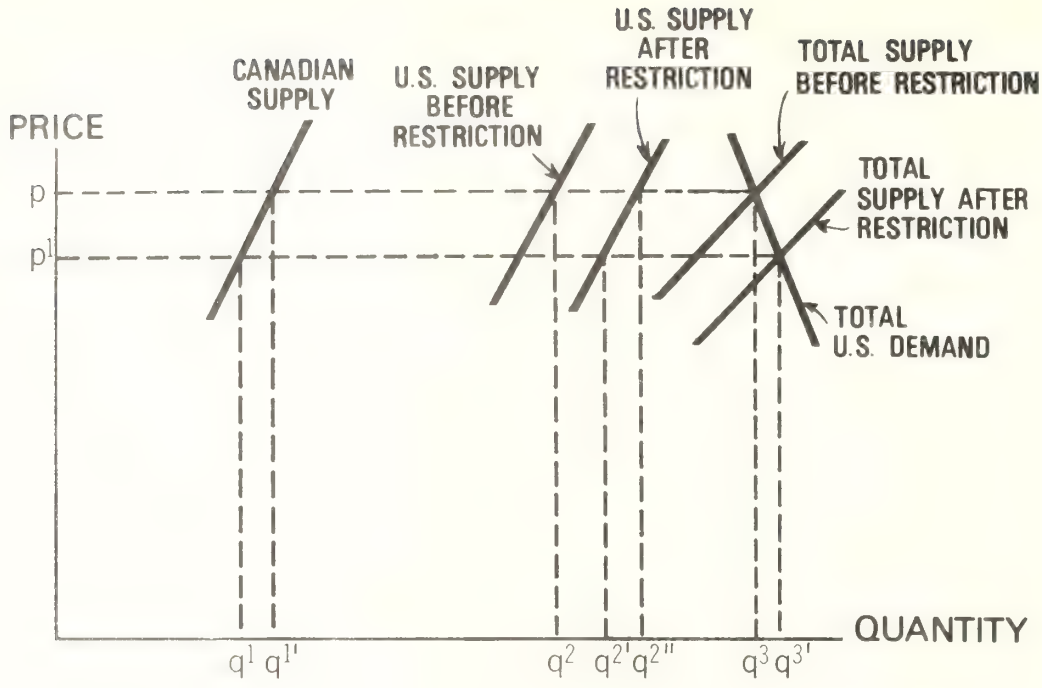

Figure 2.--The assumed effect of an increase in the U.S. supply of western softwoods.

supply in figure 2 is shifted to the right by the additional restrictions on softwood log exports. The shift in the total U.S. supply schedule shifts the intersection with total U.S. demand downward to a lower price, P^1. In the example shown in figure 2, Canadian producers are willing to produce less at the lower price so Canadian imports decline from q^1 to $q^{1'}$. If U.S. producers did not respond to the lower price by reducing output, U.S. supply of western softwood lumber would have increased from q^2 to $q^{2''}$. Because of the decline in production due to lower prices, U.S. supply only increases from q^2 to $q^{2'}$. Consumers respond to lower prices by increasing their purchases. In total, U.S. consumption would increase from q^3 to $q^{3'}$ following the increase in supply.

The changes in price from P to P^1 depend on two factors: the direction, extent, and timing of the shift in the U.S. supply schedule and the responsiveness of U.S. consumers, U.S. producers, and Canadian producers to changes in prices. The first factor is surrounded by uncertainty as there is little consensus among interested groups on either the direction or extent to which the U.S. supply would shift following a restriction of log exports. Figure 2 illustrates only the case where the U.S. supply curve shifts out by some amount. In the case where U.S. supply is decreased (because of increased foreign demand), the price change would be in the opposite direction. That is, prices would increase following a restriction of log exports.

In figure 2, both consumers and producers are assumed to be price responsive, implying that amounts demanded and supplied change as price changes. The responsiveness of either supply or demand to changes in price

s measured by the elasticity of the upply or demand schedule. The lasticity (ε) of either schedule is alculated as the percentage change in uantity (q) divided by the percentage hange in price (p):

$$\varepsilon = \Delta q/q/\Delta p/p. \quad (1)$$

f a percentage change in price is ccompanied by a larger percentage hange in quantity, the supply or emand schedule is termed elastic. If percentage change in price is accom-anied by a smaller percentage change n quantity, supply or demand is termed nelastic.

Although supply and demand elastici-ies help determine the price impacts f shifts in supply depicted in figure 2, here is little agreement among industry nalysts on the appropriate values for ither supply or demand elasticities.

HE APPROACH USED IN THE ANALYSIS

The general approach used in this nalysis was to first estimate price hanges associated with two extreme cenarios of events. These price hanges establish a range which would ct as boundaries to other estimates of rice changes. The second part of the pproach was to test the sensitivity of rice changes to changes in: (1) the lasticity estimates associated with he supply and demand schedules depicted n figure 1 and (2) the volume of logs mplied by the shift in lumber supply llustrated in figure 2.

This analysis is based on expressing he conceptual framework illustrated in igures 1 and 2 analytically as a sys-em of equations. This analytical odel is based, for each year, on eveloping supply and demand equations nd solving them simultaneously for umber price given the actual quantity lus additional quantity derived from ogs formerly exported. Stumpage rices are then derived from lumber rices in such a way that a change in lumber prices is also reflected in a change in stumpage prices. The specification and solution of the analytical model is discussed in appendix A.

In general, the stumpage market is considered to be less elastic than the lumber market because the demand for stumpage is derived from the demand for lumber. This implies that stumpage prices change at a relatively faster rate than do lumber prices.

EXTREME SCENARIOS

The extreme scenarios deal with the direction of the shift in the U.S. supply schedule induced by a restriction of log exports. The first alternative deals with a situation where mills may be operating short of capacity and a log export restriction increases the amount of domestic production. In this case the U.S. supply schedule is assumed to shift outward by the amount of formerly exported timber which is now being processed for domestic use. The total supply curve shifts outward and is accompanied by a decline in prices. The second alternative deals with a situation where mills may be operating at capacity and a log export restriction increases the foreign demand for western softwood lumber. In this case, the quantity of softwood lumber available to U.S. consumers declines resulting in the total supply curve shifting inward (to the left). This movement is accompanied by an increase in prices.

VALUES FOR THE MAJOR ASSUMPTIONS

To implement an analytical model based on the economic framework illustrated in figure 1 requires a number of assumptions specifying values for the supply and demand elasticities and the direction, extent, and timing in the shift of the U.S. supply schedule. This study considers a range of values for each assumption since little consensus exists for the values of any particular assumption. This range is

established by two extreme values and one value from near the midpoint of the range. Three values provide enough information to determine the shape (linear or nonlinear) of the relationship between price changes and levels for each assumption.

The time frame of the analysis is 1973 through 1975. Using prices and quantities for this period implies that the computed price changes represent a hypothetical ban on log exports effective January 1, 1973. This approach avoids the need for projections of prices and quantities which themselves may be suspect. These results can be generalized to other time periods by extrapolating the price impacts for the 1973-75 period in a linear fashion. The data are discussed in appendix B.

Induced Shifts in Supply

The lumber and stumpage price impacts depend, in part, on how much the total supply curve shifts following a restriction of log exports in 1973. In the approach used in this analysis, different assumptions were made about the extent and timing of shifts in the supply schedule of western softwood lumber. Three assumptions were adopted for the extent of supply shifts. The first assumption was that the U.S. supply schedule was not affected by a change in log export policy. The second assumption specifies that the U.S. supply schedule shifts by the lumber equivalent of 50 percent of the logs exported in 1973. The last assumption specifies that the U.S. supply schedule shifts by the lumber equivalent of 100 percent of the logs exported in 1973. In addition, three assumptions were made defining the timing of the supply shifts. These assumptions, involving the extent and timing of supply shifts, lead to the seven assumptions shown in table 1. The assumed maximum change in volume was 3.4 billion board feet (lumber scale). This is equivalent to the volume of logs exported from Washington, Oregon, and California in 1973.

The assumptions in table 1 show how much the supply schedule shifts in

Table 1--*Assumptions about the extent and timing of the total supply shifts following a restriction of log exports in 1973*

(Billion board feet, lumber scale)

Year	Assumptions						
	I[1]	II[2]	III[2]	IV[2]	V[3]	VI[3]	VII[3]
1973	0	1.70	0.68	1.02	3.40	1.36	2.04
1974	0	0	.51	.51	0	1.02	1.02
1975	0	0	.51	.17	0	1.02	.34

[1]Assumes that the U.S. supply curve was not affected by a change in log export policy.

[2]Assumes that the U.S. supply curve shifts (over a 3-year period) by the lumber equivalent of 50 percent of the logs exported in 1973.

[3]Assumes that the U.S. supply curve shifts (over a 3-year period) by the lumber equivalent of 100 percent of the logs exported in 1973.

each of the 3 years under consideration. For example, the sixth assumption implies that the U.S. supply curve shifts by 1.36 billion board feet in 1973 and 1.02 billion board feet in 1974 and 1975. The directions of the shifts depend on the scenario of economic events adopted.

The seven assumptions listed in table 1 apply to both inward and outward shifts in the U.S. supply schedule. For example, the fifth assumption states that the U.S. supply schedule either shifts outward or inward by 3.4 billion board feet. If the schedule shifts outward then the U.S. supply has expanded assuming foreign consumers of U.S. softwood logs have not increased their consumption of U.S. lumber and that domestic processing capacity is available. An inward shift implies that foreign consumers have increased their consumption of U.S. lumber to offset the volume of logs they formerly imported. In tight markets this would lead, still considering assumption V, to a 3.4 billion-board-foot reduction in supply. In more normal times or considering less than a total offset by foreign consumers, this scenario of events might lead to a smaller shift in the U.S. supply schedule.

Demand and Supply Elasticities

The price changes associated with a shift in the U.S. supply curve attributable to a restriction of log exports depend not only on the shift but also on the extent to which there is movement along both the supply and demand curves. This movement is determined by the elasticities assumed for the supply and demand schedules.

Estimates of the elasticity of the U.S. demand for softwood lumber have ranged from roughly -0.2 to -1.6 (Adams 1974, and Adams and Blackwell 1974). In this analysis, the price impacts of the shifts in the U.S. supply of western softwood lumber were calculated for three estimates of the elasticity associated with the U.S. demand schedule for western softwood lumber: -0.2, -0.8, and -1.6. These elasticities reflect the tastes and preferences of lumber consumers which are slow to change. Hence, these estimates are applicable to each of the 3 years included in the model.

Estimates of the elasticity of the U.S. supply schedule for western softwoods have ranged from roughly 0.6 to 1.6 (Adams[1] and Mills and Manthy 1974). In this analysis, the price impacts of shifts in U.S. supply of western softwood lumber were calculated assuming supply elasticities of 0.6, 1.0, and 1.6. The supply elasticity estimates remain the same throughout the 3-year period because the collective behavior of producers is fairly stable for such a short period. In longer periods, however, supply elasticities are usually seen as being more volatile than demand elasticities because they are based on the behavior of a smaller number of individuals.

No information is available on the elasticity of the Canadian supply schedule in the U.S. market for western softwoods. Manning (1975) found that the Canadian domestic market is directly tied to the U.S. market, and both lumber supply and demand schedules are inelastic. In this analysis, the Canadian supply elasticity was arbitrarily assumed to be less than, equal to, or greater than the estimate for the U.S. supply schedule. These assumptions are shown in table 2.

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[1]Adams, Darius M. 1976. Further simulations of the price effects of shifts in National Forest harvest schedules. 10 p., plus appendixes. Unpublished report prepared for USDA For. Serv., Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Table 2--*Assumptions about Canadian supply elasticities compared to U.S. supply elasticities*

Supply elasticity	Estimates		
United States	0.6	1.0	1.6
Canadian			
less than U.S.	.4	.8	1.4
equal to U.S.	.6	1.0	1.6
greater than U.S.	.8	1.2	1.8

PRICE IMPACTS OF A RESTRICTION ON LOG EXPORTS

Price changes attributable to a change in supply induced by a restriction of log exports are shown in tabular form in appendix C. A total of 756 price changes were computed for the various combinations of assumptions. The procedure was to first specify the elasticities of the two regional supply functions and the national demand function. Given these elasticities, the next step was to quantify the demand and supply schedules using the technique discussed in appendix A. The next step involves selecting from table 1 an assumption about the extent and timing of the supply shift and making an assumption about the direction of the shift. With this information, the change in lumber prices and the corresponding change in stumpage prices were calculated.

In appendix C, the results are compiled into nine tables; and the selection of any one table depends on the two related assumptions about U.S. and Canadian supply elasticities. A guide to the tables is presented in appendix C.

As an example, suppose the following specific assumption had been made: U.S. and Canadian supply elasticities are 1.0 and 0.8 respectively. This would lead to the selection of table 6 in appendix C. Further, assume that the supply curve shifts outward by 1.70 billion board feet following a restriction of log exports. The price impacts (in percentage terms) associated with these events are shown in the following tabulation.

Demand elasticity estimate of a restriction on log exports	Assumption about the supply shift[2]		
	II	III	IV
	Lumber		
	Percent impact on price		
-0.20	4.5	5.3	5.0
-0.80	3.0	3.5	3.3
-1.60	2.0	2.4	2.3
	Stumpage		
	Percent impact on price		
-.115	8.5	8.9	8.6
-.461	5.6	5.8	5.6
-.922	3.9	4.0	3.9

[2]See table 1.

Given the tabular information, the remaining assumptions deal with the value for the demand elasticity and the timing of the shifts in the U.S. supply schedule. Continuing the example, suppose that the demand elasticity is -0.8 and that the supply shift occurs in 1973 (assumption II, table 1). Therefore, the price impact of a restriction on log exports is 3.0 percent in the lumber market and 5.6 percent in the stumpage market. That is, lumber prices are decreased by $6.08 per thousand board feet (from $204.80 per thousand to $198.72 per thousand).

In the analysis, price changes measured in dollars are the same in both lumber and stumpage markets. In the example, stumpage prices also decrease by $6.08 per thousand (from $107.81 per thousand to $101.73 per thousand). The percent changes, however, differ as shown in the tabulation. Parallel changes in each market result from the approach used to link the markets and are explained in appendix A.

THE RANGE OF PRICE IMPACTS

The range of prices and price impacts found in this analysis is as follows:

	Price (supply curve shifts outward)		Average 1973-75 price	Price (supply curve shifts inward)	
	(Dollars)	(Percent)	(Dollars)	(Dollars)	(Percent)
Lumber	174.12	-15.8	206.71	242.71	17.4
Stumpage	90.27	-26.5	122.86	158.92	29.3

The assumptions underlying these price changes were that the U.S. demand, U.S. supply, and Canadian supply elasticities were -0.2, 0.6, and 0.4, respectively, and that the U.S. supply curve was assumed to shift in each of the 3 years by the amount shown for assumption VI in table 1.

The range establishes the limits but provides little information on which to base expectations regarding possible price changes associated with less extreme assumption combinations. This information is best given by the distribution of price changes over various dollar intervals. In this analysis, there are 378 possible price changes associated with the lumber market. The distribution of these price changes is shown by the following:

Price interval	Percent of price changes
(Dollars)	
0- 5	26.5
5-10	35.2
10-15	21.7
15-25	12.4
25+	4.2

Based on these values, most of the price changes (61.7 percent) associated with the various combinations of assumptions are $10 or less and in only 16.6 percent of the assumption combinations would the price change be greater than $15 per thousand board feet.

SENSITIVITY OF PRICE CHANGES TO EACH ASSUMPTION

The analysis presented in this paper is an example of the use of a partial-equilibrium analysis to depict an equilibrium situation. One variable--the U.S. supply schedule--is changed; other factors are assumed constant and the new equilibrium position is observed. This method is useful in illustrating the influence of a supply shift on lumber and stumpage prices, but it may be somewhat misleading when applied to a "real world" situation where other factors may change.

The extent to which the supply schedule shifts depends on the volume of logs formerly exported being processed for the domestic market. Given the shift in the U.S. supply schedule, the magnitude of the price impact is determined by the estimates of the elasticities of the U.S. demand and the U.S. and Canadian supply schedules. The ranges of the elasticity estimates used in this analysis bracket published estimates. This raises the issue of the sensitivity of the price impacts associated with a shift in supply. If the price impacts of further softwood log export restrictions are sensitive to these elasticity assumptions, then this adds further uncertainty to the ability of a model to assess the impacts of a change in trade policy.

In order to assess the sensitivity of lumber and correspondingly stumpage price changes to the value of the elasticity of either lumber supply or demand requires that all other components of the market structure be specified. The data used in the remainder of this section of the report are drawn from the tables in appendix C and show the price changes associated with an inward shift in the supply schedule under various assumptions about supply and demand elasticities.

One major concern is the sensitivity of price impacts to various estimates of the U.S. and Canadian supply elasticities. In general, price changes vary inversely with the magnitude of elasticity estimates. That is, the more inelastic an estimate is, the greater will be the change in price following a change in quantity. Figure 3 illustrates this relationship assuming the demand elasticity is equal to -0.2 and that, in 1973, 100 percent of the restricted logs are domestically processed (assumption V, table 1). The figure shows that price impacts become

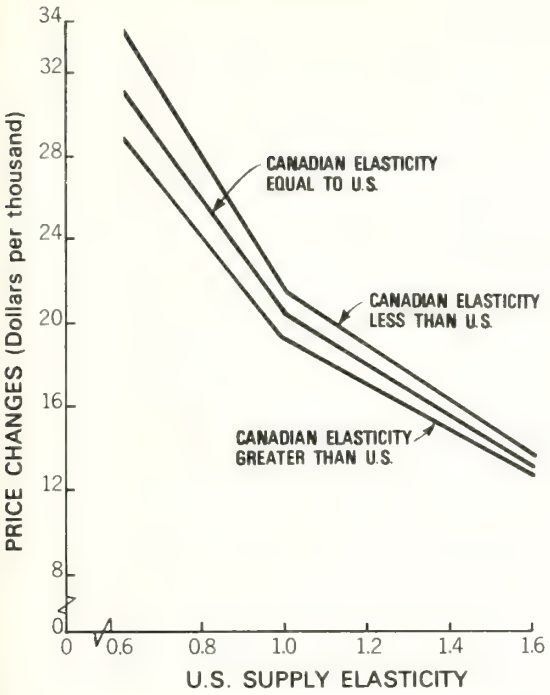

Figure 3.--Sensitivity of lumber price changes to U.S. and Canadian supply elasticity estimates.

more sensitive as the estimates of elasticity become more inelastic. Hence, any small error in the elasticity estimate may have a serious impact on the estimate of price change. For example, the difference in price changes between elasticity estimates of 0.6 and 0.8 range from roughly $5 to $6 depending on the Canadian supply elasticity. At the other extreme portion of the curve, the difference in price impacts--associated with U.S. supply elasticity estimates of 1.4 and 1.6--range from roughly $1 to $2.

Figure 3 also illustrates the influence of various estimates of the Canadian supply elasticities on price changes resulting from an inward shift in the U.S. supply schedule. The difference in price changes varies from roughly $5 assuming a supply elasticity of 0.6 to $1 assuming a supply elasticity of 1.6. The likelihood of a serious error in the estimated price change is increased as the supply elasticity becomes more inelastic.

The sensitivity of price changes following a supply shift induced by log export restrictions to different estimates of the demand elasticity are shown in figure 4. The price changes in figure 4 reflect U.S. and Canadian supply elasticities of 0.6 and 0.4. In figure 4, the relationship is downward sloping indicating that price changes are inversely related to demand elasticity estimates. For example the price change associated with a demand elasticity estimate of -0.2 is three times as great as that associated with an estimate of -1.6. Figure 4 also shows the effect of assuming different time paths for processing the volume of logs affected by the restriction. There is little difference between the estimates because the price of softwood lumber has remained relatively unchanged during the period 1973-75.

In figure 4 the U.S. supply schedule was assumed to shift inward. If it were assumed to shift outward, the relationship shown in figure 4 would be slightly lower but still very similar to what is shown.

The relationship between price changes and the assumed changes in the amount of restricted logs processed is linear. That is, the magnitude of price changes varies directly with the quantity processed. Given the assumptions underlying figure 4, a doubling of the quantity processed leads to price changes which are roughly doubled.

SUMMARY

This study has shown, for alternative softwood lumber market structures, the potential impacts on western softwood lumber and stumpage prices assuming softwood log exports had been banned at the beginning of 1973. The components of each market structure consisted of a supply schedule for western softwood lumber (produced in the United States), a supply schedule for softwood lumber imports from Canada, and a U.S. demand schedule for western softwood

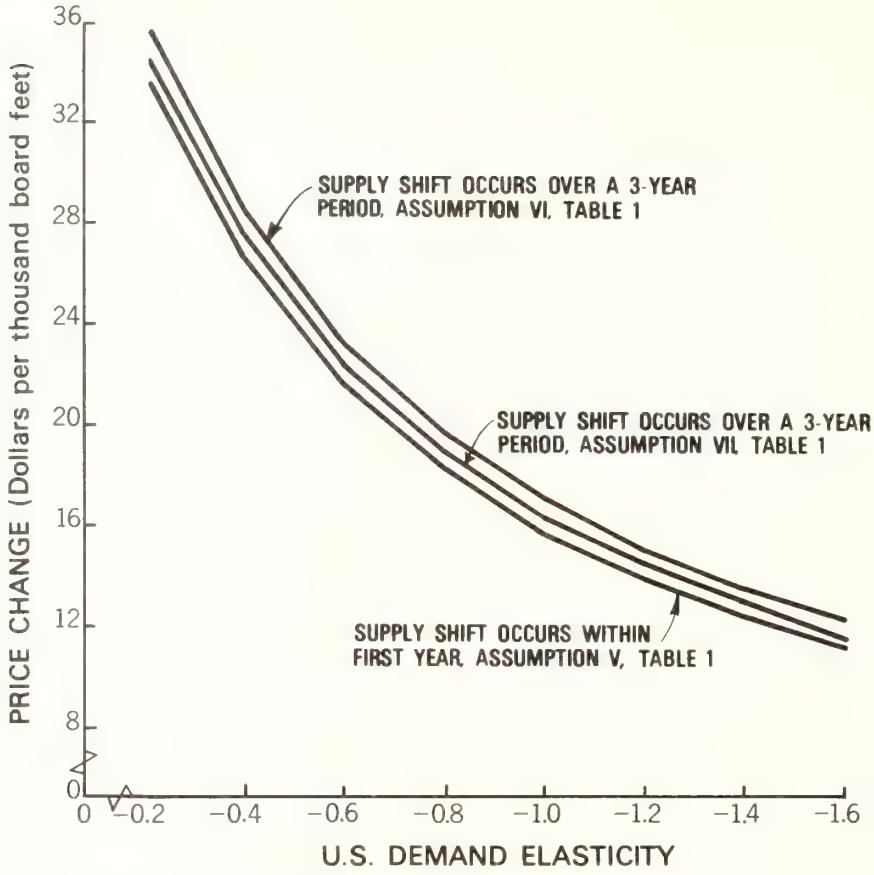

Figure 4.--Sensitivity of lumber price impacts to U.S. demand elasticity estimates.

lumber. Stumpage price changes were included by linking them to lumber price changes. The procedure used in the study was to assume that the ban on softwood log exports shifted the U.S. supply schedule for western softwoods in either direction and by varying amounts over the period 1973-75. The resulting lumber and stumpage price impacts were shown to depend on the elasticities assumed for the supply and demand schedules hypothesized in the market structure.

The study was not designed to predict lumber and stumpage price changes associated with a ban on log exports. The market structures assumed in the study did not include provisions for either the possible trade-offs between foreign and domestic consumption or processing capacity constraints on U.S. lumber and stumpage prices. The actual effects on prices in the event of a ban on softwood log exports would depend heavily on current market conditions and producer and consumer reactions at the time of the change in trade policy. Reasonable rationales could be developed for either price increases or price decreases in the event of further restrictions of softwood log exports.

The study does provide an estimate of the extreme changes in western softwood lumber and stumpage prices which could have been associated with

a ban on softwood log exports at the beginning of 1973. Assuming the most inelastic supply and demand schedule, the analysis shows that the lumber price change between extremes would range from a decrease of 16 percent to an increase of 17 percent. The analysis shows stumpage price changes ranging from a decrease of 26 percent to an increase of 29 percent. Changes in foreign demand, possible capacity limits, and differences in timber species between logs processed domestically and exported would probably tend to offset some of these price changes.

The maximum percentage change in lumber and stumpage prices calculated in this study for 1973-75 was based on data for a period when markets were both tight (1973) and depressed (1975). Although the maximum percentage change for any future modification in trade policy would tend to vary according to market conditions, the extremes of the market structure hypothesized in this study make the estimate for 1973-75 a reasonable indicator for future changes in policy.

The study found western softwood lumber and stumpage prices to be sensitive to the elasticities used for the supply and demand schedules in the assumed market structure. The study also demonstrated that stumpage price changes are greater (in percent terms) than the corresponding lumber price changes. This is consistent with the differences in demand elasticities between the lumber and stumpage markets. For stumpage in Washington and Oregon, the percentage change in stumpage prices was on the order of 1.6 times the percentage change in lumber prices. Stumpage prices would probably change by more than this in the State of Washington where the log export industry is concentrated.

The study does not resolve the debate over what might happen to lumber and stumpage prices if softwood log exports were to be banned. The study does place both an upper and lower limit on the possible change in prices which might occur if trade policy were to change. The study further defines the sensitivity of price changes to the values for the elasticities of supply and demand schedules. This finding adds to rather than clarifies the uncertainty surrounding the trade-offs from different trade policies. The demonstrated sensitivity of price changes to these technical parameters of of forest product markets demonstrates their importance in any analysis of the impacts of a change in trade policy. Using a range of elasticities which bracketed published estimates of these market parameters, lumber price was found to vary by as much as 11 percent according to which elasticity was assumed for the U.S. demand schedule and 10 percent for the assumptions about the supply schedules. There is little agreement among industry analysts on the appropriate values to be assigned to the supply and demand schedules used in this study.

As expected, the effects of further restrictions of softwood log exports on prices were especially sensitive to how much this change in trade policy would shift the U.S. softwood lumber supply schedule. This study shows the effects on prices for a number of supply shifts, but does not provide any rationale for predicting the magnitude of any shift which might occur in the event of a change in trade policy.

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APPENDIX A

SPECIFICATION AND SOLUTION OF THE ANALYTICAL MODEL

The specification of the analytical model involves three types of relationships: (1) the specification and solution of the supply and demand functions, (2) between lumber and stumpage prices, and (3) between lumber and stumpage elasticities. The functional expressions used in this appendix are expressed in logarithmic form in an attempt to facilitate interpretation.[1]

Specification and Solution of the Supply and Demand Functions

The supply and demand functions employed in the analytical model were not estimated from time series data but rather solved for some year given the market price, quantity, and an estimate of elasticity. The development of these relationships began with the assumption that the form of the relationship between price and quantity was hyperbolic which has the property of constant elasticity. This functional form could be expressed as

$$q = \alpha\, p^{\varepsilon} \qquad (2)$$

$$\text{or } \ln q = \ln\alpha + \varepsilon \ln p;$$

where α is a constant and the sign associated with ε is positive for supply functions and negative for demand functions. Equation 2 can be rewritten so that quantity is expressed in terms of known variables. For the national demand function, equation 2 can be rewritten as

$$\ln q = \ln\hat{q} + \varepsilon\,(\ln\hat{p} - \ln p); \qquad (3)$$

where $\hat{q}$ and $\hat{p}$ are reported quantities and prices for a given year. For the Canadian and U.S. supply functions, equation 2 can be rewritten as

$$\ln q = \ln\hat{q} + \varepsilon\,(\ln p - \ln\hat{p}). \qquad (4)$$

In both equations the sign of ε is positive.

The determination of price and quantity requires the simultaneous solution of the national demand function (equation 3) and the Canadian and U.S. supply functions (in the form of equation 4). In this case, the system of three equations was solved by an iterative procedure in which, by slightly changing price, each iteration converged on the correct solution.

The use of logarithms introduces a slightly different economic interpretation of the demand curve. In this case, the curve is interpreted as exhibiting constant rather than variable elasticity as is the case with linear demand curves. With linear curves, a percentage change in price is accompanied by a progressively smaller percentage change in quantity. When log-linear curves are adopted, a given percentage change in price is accompanied by corresponding[2] percentage change in quantity irrespective of the magnitude of quantity. In this report, this limitation is not a major concern because the computed price changes are not located in the extreme portions of the curves.

[1] Often demand and supply curves are expressed in logarithms (which measure percentage changes) so that the slope and the elasticity of the function are equivalent.

[2] If the elasticity was assumed to be 1 then the percentage changes would be exactly the same.

Linkage Between Lumber and Stumpage Markets

This study has considered the effect of a change in stumpage supply only as it is reflected in changes in the lumber market. This creates the problem of how to translate a change in lumber price into the corresponding change in stumpage price. In the analytical framework, the linkage between stumpage and lumber markets was described by two relationships. These relationships are based on derived demand concepts and assume the elasticity of substitution between stumpage and other factors of production to be zero. It assumes that the price difference between the two markets is a constant and can be expressed as

$$p^S = p^L - m; \qquad (5)$$

where p^S is the price of stumpage,

p^L is the price of lumber, and

m is a constant equal to the difference between p^S and p^L.

In this case, the lumber and stumpage demand curves would be seen as being parallel to each other. Given the assumptions made for the previous equation, an expression can be developed relating the elasticity in the stumpage market to the elasticity in the lumber market. The proof of this relationship is presented in a study by George and King (1971). This relationship is expressed as

$$e^S = e^L \, p^S/p^L; \qquad (6)$$

where the superscripts refer to the stumpage and lumber markets.

The wholesale lumber price will always be greater than the stumpage price. Thus, the price ratio p^S/p^L will always be less than one implying the e^S will always be less elastic than e^L.

APPENDIX B

DATA USED IN THE ANALYSIS

Data covering a 3-year period are necessary to support the assumption that a 3-year period may be required for logs to enter the domestic market. The most recent period (1973 through 1975) was chosen because it reflects price trends which are likely to continue in the near future. Admittedly, this is not a typical period because of the swings which took place in forest products markets, but the resulting price impacts represent an upper limit to what might be expected. These results can be generalized to other time periods by extrapolating the price impacts for the 1973-75 period in a linear fashion.

In the development of the analytical model, western softwood data were used because the majority of the log exports are from the west coast and any additional lumber output derived from the logs would enter the market as western softwood lumber. In addition, the majority of Canadian imports are western softwoods and as such are generally substitutable for western softwood lumber produced in the United States. Western softwood lumber production was used for the quantity data while Douglas-fir lumber prices were used as a proxy for western softwood lumber prices. The supply equation for Canadian exports, to the United States, also used Douglas-fir lumber prices. These data are shown in table 3.

Table 3--*Price and quantity data used in the study*

Required data	Unit column	1973	1974	1975
Douglas-fir lumber price[1]	Dollars per thousand	204.8	208.81	207.14
Western softwood lumber production[2]	Billion board feet	22.6	19.7	18.7
U.S. lumber imports from Canada[2]	Billion board feet	8.84	6.73	5.68
Stumpage price in western Washington and Oregon[3]	Dollars per thousand	107.81	146.41	119.38

[1]Price per thousand board feet, converted to dollars from the wholesale price index.

[2]Billion board feet, from "The Demand and Price Situation for Forest Products," by Robert B. Phelps, USDA For. Serv. Misc. Publ. 1315, p. 85, 1975.

[3]Price per thousand board feet, average of Forest Service bids in western Washington and Oregon.

APPENDIX C

PRICE CHANGES INDUCED BY A LOG EXPORT RESTRICTION

The lumber and stumpage price changes induced by log export restrictions are shown in this appendix. The table numbers associated with each of the possible combinations of U.S. and Canadian supply elasticities are shown in table 4. In general, price changes are expressed as the percentage change per thousand board feet (MBF) and are shown in tables 5-13. To convert percentage changes to a dollar basis, multiply the percentage change by the prices given in the notes for each table. For example, if the percentage change was 6.77 percent for the second assumption (II) about the supply curve shifting outward, then the dollar price change would be $13.86 per MBF lumber scale.

Table 4--*Guide to tables 5-13*

Table number	U.S. supply elasticity	Canadian supply elasticity
5	0.6	0.4
6	1.0	0.8
7	1.6	1.4
8	0.6	0.6
9	1.0	1.0
10	1.6	1.6
11	0.6	0.8
12	1.0	1.2
13	1.6	1.8

TABLE 5 PRICE CHANGES FOLLOWING A SHIFT IN THE U.S. SUPPLY CURVE[1]

ELASTICITY ESTIMATE	NO SHIFT	PRICE CHANGES PER THOUSAND BOARD FEET EXPRESSED IN PERCENTAGE TERMS[2]											
		SUPPLY CURVE SHIFTS OUTWARD[3]						SUPPLY CURVE SHIFTS INWARD[3]					
		II	III	IV	V	VI	VII	II	III	IV	V	VI	VII
						LUMBER							
-.2000	0.00	6.81	8.07	7.63	12.80	15.77	14.82	7.82	8.48	8.13	16.78	17.44	16.85
-.8000	0.00	3.84	4.49	4.23	7.34	8.84	8.34	4.23	4.69	4.48	8.94	9.53	9.15
-1.6000	0.00	2.43	2.83	2.68	4.66	5.59	5.27	2.63	2.95	2.81	5.51	5.95	5.70
						STUMPAGE							
-.1153	0.00	12.95	13.58	13.06	24.32	26.53	25.36	14.85	14.25	13.91	31.87	29.35	28.82
-.4611	0.00	7.29	7.55	7.23	13.94	14.88	14.26	8.03	7.90	7.66	16.98	16.03	15.65
-.9221	0.00	4.61	4.77	4.59	8.86	9.46	9.02	5.00	4.96	4.80	10.47	10.02	9.75

[1]ASSUMING U.S. AND CANADIAN SUPPLY ELASTICITIES ARE 0.6 AND 0.4, RESPECTIVELY.

[2]TO CONVERT PRICE CHANGES INTO DOLLARS, MULTIPLY CHANGES BY THE FOLLOWING PRICES:

	ASSUMPTION		
	II+V	III+VI	IV+VII
LUMBER	204.80	206.71	206.24
STUMPAGE	107.81	122.86	120.55

[3]THE ASSUMPTIONS ABOUT THE EXTENT AND TIMING OF SUPPLY SHIFTS ARE AS FOLLOWS:

ASSUMPTION	1973	1974	1975
	(BILLION BOARD FEET)		
II	1.70	0.00	0.00
III	.68	.51	.51
IV	1.02	.51	.17
V	3.4	0	0
VI	1.36	1.02	1.02
VII	2.04	1.02	.34

TABLE 6 PRICE CHANGES FOLLOWING A SHIFT IN THE U.S. SUPPLY CURVE[1]

ELASTICITY ESTIMATE	NO SHIFT	PRICE CHANGES PER THOUSAND BOARD FEET EXPRESSED IN PERCENTAGE TERMS[2]											
		SUPPLY CURVE SHIFTS OUTWARD[3]						SUPPLY CURVE SHIFTS INWARD[3]					
		II	III	IV	V	VI	VII	II	III	IV	V	VI	VII
						LUMBER							
-.2000	0.00	4.48	5.26	5.00	8.55	10.35	9.74	4.98	5.49	5.24	10.59	11.25	10.78
-.8000	0.00	2.97	3.47	3.27	5.69	6.85	6.47	3.24	3.61	3.44	6.81	7.34	7.04
-1.6000	0.00	2.05	2.38	2.26	3.94	4.71	4.45	2.21	2.47	2.34	4.62	5.02	4.80
						STUMPAGE							
-.1153	0.00	8.51	8.89	8.55	16.24	17.41	16.66	9.47	9.23	8.96	20.11	18.93	18.45
-.4611	0.00	5.64	5.84	5.60	10.82	11.52	11.07	6.16	6.07	5.89	12.95	12.34	12.04
-.9221	0.00	3.89	4.01	3.87	7.49	7.92	7.62	4.20	4.16	4.01	8.77	8.45	8.20

[1]ASSUMING U.S. AND CANADIAN SUPPLY ELASTICITIES ARE 1.0 AND 0.8, RESPECTIVELY.

[2]TO CONVERT PRICE CHANGES INTO DOLLARS, MULTIPLY CHANGES BY THE FOLLOWING PRICES:

	ASSUMPTION		
	II+V	III+VI	IV+VII
LUMBER	204.80	206.71	206.24
STUMPAGE	107.81	122.86	120.55

[3]THE ASSUMPTIONS ABOUT THE EXTENT AND TIMING OF SUPPLY SHIFTS ARE AS FOLLOWS:

ASSUMPTION	1973	1974	1975
	(BILLION BOARD FEET)		
II	1.70	0.00	0.00
III	.68	.51	.51
IV	1.02	.51	.17
V	3.4	0	0
VI	1.36	1.02	1.02
VII	2.04	1.02	.34

TABLE 7 PRICE CHANGES FOLLOWING A SHIFT IN THE U.S. SUPPLY CURVE[1]

ELASTICITY ESTIMATE	NO SHIFT	PRICE CHANGES PER THOUSAND BOARD FEET EXPRESSED IN PERCENTAGE TERMS[2]											
		SUPPLY CURVE SHIFTS OUTWARD[3]						SUPPLY CURVE SHIFTS INWARD[3]					
		II	III	IV	V	VI	VII	II	III	IV	V	VI	VII
						LUMBER							
-.2000	0.00	2.97	3.47	3.27	5.69	6.85	6.47	3.24	3.61	3.44	6.81	7.34	7.04
-.8000	0.00	2.22	2.60	2.45	4.27	5.14	4.53	2.40	2.68	2.55	5.02	5.43	5.19
-1.6000	0.00	1.66	1.94	1.83	3.21	3.82	3.61	1.79	2.00	1.90	3.71	4.05	3.88
						STUMPAGE							
-.1153	0.00	5.64	5.84	5.66	10.82	11.52	11.07	6.16	6.07	5.89	12.95	12.34	12.04
-.4611	0.00	4.22	4.37	4.25	8.12	8.58	8.20	4.57	4.50	4.36	9.53	9.14	8.89
-.9221	0.00	3.15	3.26	3.13	6.11	6.43	6.18	3.39	3.36	3.25	7.05	6.81	6.63

[1]ASSUMING U.S. AND CANADIAN SUPPLY ELASTICITIES ARE 1.6 AND 1.4, RESPECTIVELY.

[2]TO CONVERT PRICE CHANGES INTO DOLLARS, MULTIPLY CHANGES BY THE FOLLOWING PRICES:

	ASSUMPTION		
	II+V	III+VI	IV+VII
LUMBER	204.80	206.71	206.24
STUMPAGE	107.81	122.86	120.55

[3]THE ASSUMPTIONS ABOUT THE EXTENT AND TIMING OF SUPPLY SHIFTS ARE AS FOLLOWS:

ASSUMPTION	1973	1974	1975
	(BILLION BOARD FEET)		
II	1.70	0.00	0.00
III	.68	.51	.51
IV	1.02	.51	.17
V	3.4	0	0
VI	1.36	1.02	1.02
VII	2.04	1.02	.34

TABLE 8 PRICE CHANGES FOLLOWING A SHIFT IN THE U.S. SUPPLY CURVE[1]

ELASTICITY ESTIMATE	NO SHIFT	PRICE CHANGES PER THOUSAND BOARD FEET EXPRESSED IN PERCENTAGE TERMS[2]											
		SUPPLY CURVE SHIFTS OUTWARD[3]						SUPPLY CURVE SHIFTS INWARD[3]					
		II	III	IV	V	VI	VII	II	III	IV	V	VI	VII
						LUMBER							
-.2000	0.00	6.36	7.57	7.15	12.04	14.77	13.89	7.18	7.94	7.59	15.36	18.22	15.53
-.8000	0.00	3.69	4.33	4.09	7.07	8.52	8.06	4.05	4.49	4.27	8.53	9.17	8.77
-1.6000	0.00	2.37	2.76	2.63	4.56	5.45	5.16	2.56	2.83	2.73	5.34	5.82	5.54
						STUMPAGE							
-.1153	0.00	12.68	12.74	12.24	22.88	24.85	23.77	13.64	13.35	12.98	29.19	27.29	26.57
-.4611	0.00	7.01	7.29	7.00	13.42	14.34	13.79	7.68	7.55	7.31	16.20	15.43	15.00
-.9221	0.00	4.53	4.64	4.49	8.66	9.18	8.83	4.87	4.85	4.67	10.14	9.79	9.48

[1]ASSUMING U.S. AND CANADIAN SUPPLY ELASTICITIES ARE 0.6 AND 0.6, RESPECTIVELY.

[2]TO CONVERT PRICE CHANGES INTO DOLLARS, MULTIPLY CHANGES BY THE FOLLOWING PRICES:

	ASSUMPTION		
	II+V	III+VI	IV+VII
LUMBER	204.80	206.71	206.24
STUMPAGE	107.81	122.86	120.55

[3]THE ASSUMPTIONS ABOUT THE EXTENT AND TIMING OF SUPPLY SHIFTS ARE AS FOLLOWS:

	1973	1974	1975
	(BILLION BOARD FEET)		
ASSUMPTION			
II	1.70	0.00	0.00
III	.68	.51	.51
IV	1.02	.51	.17
V	3.4	0	0
VI	1.36	1.02	1.02
VII	2.04	1.02	.34

TABLE 9 PRICE CHANGES FOLLOWING A SHIFT IN THE U.S. SUPPLY CURVE[1]

ELASTICITY ESTIMATE	NO SHIFT	PRICE CHANGES PER THOUSAND BOARD FEET EXPRESSED IN PERCENTAGE TERMS[2]											
		SUPPLY CURVE SHIFTS OUTWARD[3]						SUPPLY CURVE SHIFTS INWARD[3]					
		II	III	IV	V	VI	VII	II	III	IV	V	VI	VII
						LUMBER							
-.2000	0.00	4.30	5.06	4.80	8.21	9.92	9.33	4.76	5.24	5.02	10.01	10.71	10.28
-.8000	0.00	2.88	3.37	3.20	5.54	6.66	6.29	3.13	3.50	3.34	6.56	7.12	6.81
-1.6000	0.00	2.00	2.35	2.23	3.87	4.63	4.38	2.16	2.42	2.31	4.50	4.90	4.68
						STUMPAGE							
-.1153	0.00	8.16	8.51	8.20	15.59	16.68	15.96	9.03	8.81	8.59	19.02	18.02	17.60
-.4611	0.00	5.48	5.67	5.48	10.53	11.20	10.76	5.95	5.89	5.72	12.47	11.98	11.66
-.9221	0.00	3.80	3.95	3.81	7.36	7.78	7.49	4.11	4.06	3.95	8.55	8.24	8.01

1. [1]ASSUMING U.S. AND CANADIAN SUPPLY ELASTICITIES ARE 1.0 AND 1.0, RESPECTIVELY.
[2]TO CONVERT PRICE CHANGES INTO DOLLARS, MULTIPLY CHANGES BY THE FOLLOWING PRICES:

	ASSUMPTION		
	II+V	III+VI	IV+VII
LUMBER	204.80	206.71	206.24
STUMPAGE	107.81	122.86	120.55

[3]THE ASSUMPTIONS ABOUT THE EXTENT AND TIMING OF SUPPLY SHIFTS ARE AS FOLLOWS:

ASSUMPTION	1973	1974	1975
	(BILLION BOARD FEET)		
II	1.70	0.00	0.00
III	.68	.51	.51
IV	1.02	.51	.17
V	3.4	0	0
VI	1.36	1.02	1.02
VII	2.04	1.02	.34

TABLE 12 PRICE CHANGES FOLLOWING A SHIFT IN THE U.S. SUPPLY CURVE[1]

ELASTICITY ESTIMATE	NO SHIFT	PRICE CHANGES PER THOUSAND BOARD FEET EXPRESSED IN PERCENTAGE TERMS[2]											
		SUPPLY CURVE SHIFTS OUTWARD[3]						SUPPLY CURVE SHIFTS INWARD[3]					
		II	III	IV	V	VI	VII	II	III	IV	V	VI	VII
						LUMBER							
-.2000	0.00	4.11	4.88	4.59	7.88	9.55	8.99	4.53	5.06	4.80	9.49	10.23	9.78
-.8000	0.00	2.79	3.29	3.13	5.40	6.47	6.11	3.04	3.40	3.23	6.33	6.89	6.61
-1.6000	0.00	1.97	2.30	2.17	3.80	4.54	4.28	2.12	2.37	2.26	4.39	4.81	4.58
						STUMPAGE							
-.1153	0.00	7.82	8.26	7.85	14.98	16.07	15.38	8.60	8.51	8.20	18.02	17.22	16.74
-.4611	0.00	5.30	5.53	5.35	10.25	10.89	10.45	5.77	5.72	5.52	12.03	11.60	11.31
-.9221	0.00	3.74	3.87	3.71	7.22	7.63	7.33	4.02	3.99	3.87	8.34	8.09	7.84

[1]ASSUMING U.S. AND CANADIAN SUPPLY ELASTICITIES ARE 1.0 AND 1.2, RESPECTIVELY.

[2]TO CONVERT PRICE CHANGES INTO DOLLARS, MULTIPLY CHANGES BY THE FOLLOWING PRICES:

	ASSUMPTION		
	II+V	III+VI	IV+VII
LUMBER	204.80	206.71	206.24
STUMPAGE	107.81	122.86	120.55

[3]THE ASSUMPTIONS ABOUT THE EXTENT AND TIMING OF SUPPLY SHIFTS ARE AS FOLLOWS:

	1973	1974	1975
	(BILLION BOARD FEET)		
ASSUMPTION			
II	1.70	0.00	0.00
III	.68	.51	.51
IV	1.02	.51	.17
V	3.4	0	0
VI	1.36	1.02	1.02
VII	2.04	1.02	.34

TABLE 13 PRICE CHANGES FOLLOWING A SHIFT IN THE U.S. SUPPLY CURVE[1]

ELASTICITY ESTIMATE	NO SHIFT	PRICE CHANGES PER THOUSAND BOARD FEET EXPRESSED IN PERCENTAGE TERMS[2]											
		SUPPLY CURVE SHIFTS OUTWARD[3]						SUPPLY CURVE SHIFTS INWARD[3]					
		II	III	IV	V	VI	VII	II	III	IV	V	VI	VII
						LUMBER							
-.2000	0.00	2.79	3.29	3.13	5.40	6.47	6.11	3.04	3.40	3.23	6.33	6.89	6.61
-.8000	0.00	2.13	2.48	2.35	4.10	4.90	4.63	2.29	2.55	2.44	4.76	5.20	4.97
-1.6000	0.00	1.66	1.87	1.77	3.11	3.71	3.50	1.72	1.94	1.84	3.57	3.91	3.73
						STUMPAGE							
-.1153	0.00	5.30	5.53	5.35	10.25	10.89	10.45	5.77	5.72	5.52	12.03	11.60	11.31
-.4611	0.00	4.04	4.18	4.02	7.79	8.24	7.91	4.35	4.29	4.16	9.03	8.76	8.50
-.9221	0.00	3.04	3.15	3.03	5.90	6.24	5.99	3.26	3.26	3.15	6.78	6.57	6.38

[1]ASSUMING U.S. AND CANADIAN SUPPLY ELASTICITIES ARE 1.6 AND 1.8, RESPECTIVELY.

[2]TO CONVERT PRICE CHANGES INTO DOLLARS, MULTIPLY CHANGES BY THE FOLLOWING PRICES:

	ASSUMPTION		
	II+V	III+VI	IV+VII
LUMBER	204.80	206.71	206.24
STUMPAGE	107.81	122.86	120.55

[3]THE ASSUMPTIONS ABOUT THE EXTENT AND TIMING OF SUPPLY SHIFTS ARE AS FOLLOWS:

ASSUMPTION	1973	1974	1975
	(BILLION BOARD FEET)		
II	1.70	0.00	0.00
III	.68	.51	.51
IV	1.02	.51	.17
V	3.4	0	0
VI	1.36	1.02	1.02
VII	2.04	1.02	.34

Haynes, Richard W.
1976. Price impacts of log export restrictions under alternative assumptions. USDA For. Serv. Res. Pap. PNW-212, 25 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The impact on softwood lumber and stumpage prices of a hypothetical ban of log exports was computed for alternative assumptions about the market for western softwood lumber. The log export ban was treated as shifting the U.S. supply of western softwood. Various assumptions were made about the direction, extent, and timing of this shift. Other critical assumptions included the values for the U.S. and Canadian supply elasticities and the U.S. demand elasticity. Price changes attributed to log export restrictions were computed for each of the various combinations of assumptions.

KEYWORDS: Supply/demand (forest products), import/export (forest products), trade policy (international).

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KEYWORDS: Supply/demand (forest products), import/export (forest products), trade policy (international).

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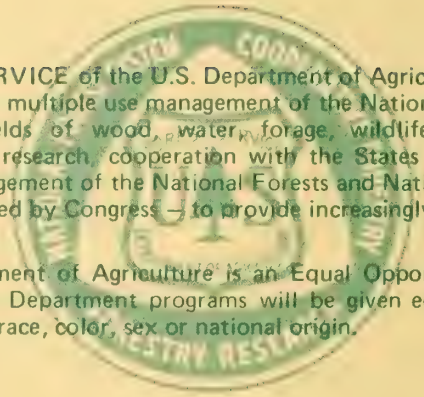

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1976

CONVERTING BRUSH AND HARDWOODS TO CONIFERS ON HIGH SITES IN WESTERN WASHINGTON AND OREGON--Progress, Policy, Success and Costs

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Edward J. Dimock II
Enoch Bell
Robert M. Randall

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

Converting Brush and Hardwoods to Conifers on High Sites in Western Washington and Oregon--Progress, Policy, Success and Costs

Reference Abstract

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Evaluates opportunities, techniques, success and cost of brushland reclamation efforts for almost a 20-year period. Among newer techniques, slash-and-burn and spray-and-burn are consistently more successful--and more economical per established conifer--than multiple-spray conversions.

KEYWORDS: Type conversion (forest), conversion (silvicultural) -)planning, reclamation (forest land), regeneration (stand), hardwoods, softwoods.

RESEARCH SUMMARY

Research Paper PNW-213

1976

Over 6.1 million acres of forest lands were surveyed in 1975 to evaluate status of brushland reclamation on ownerships managing commercial timber. These lands currently sustain 110,000 acres of brush and 757,000 acres of brush-hardwood mixtures growing on highly productive sites. Nearly all the former and about 88 percent of the latter are scheduled for eventual type conversion to higher-yielding conifers. The balance will be retained in hardwoods for either timber production or environmental protection.

During the past 20 years, 216,000 acres have already been converted to conifers by a variety of methods. Tractor scarification--with or without utilization of merchantable trees--has been the commonest reclamation technique and was used on over half the total area converted. Harvesting merchantable timber--with only incidental site preparation--was the method employed on another 23 percent of the total reclaimed. The remaining 22 percent was converted by more recently developed techniques: multiple spray, slash and burn, spray and burn, and high-lead scarify.

Success varied with all methods. Best, and least variable, results were attained on spray-and-burn and slash-and-burn conversions that generally produced good stocking and high tree density at moderately high cost. Multiple-spray conversions were cheaper on an area basis, but gave generally poorest results at more than double the cost per established conifer. Harvest-only and tractor-scarify methods were least expensive, but are best suited to easiest conversion opportunities that are becoming decreasingly common. Methods combining chemicals and fire tentatively appear to have greatest potential for future use and further development in brushland reclamation.

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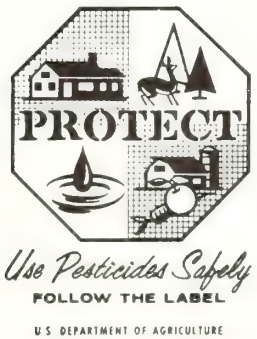

Introduction

Rehabilitation of high-site forest lands in the Pacific Northwest currently lags far behind the need. About 2.4 million acres, potentially capable of supporting valuable stands of Douglas-fir (*Pseudotsuga menziesii*) and other conifers in the Oregon-Washington Coast Ranges and the Cascade Range foothills of Washington, presently sustain plant communities of low commercial value (Gratkowski et al. 1973). These comprise either brush or brush-hardwood mixtures that are nonstocked or poorly stocked with conifers. Some of these lands are best suited to continuing production of hardwoods--but most low-value hardwood stands should be converted to more productive conifers. For the most part, these plant communities are seral stages that will eventually be replaced by climax forests typical of the *Tsuga heterophylla* and *Picea sitchensis* zones as described by Franklin and Dyrness (1973). Silvicultural methods to reclaim these lands are now available.

Brushland reclamation is neither easy nor cheap and has only been pursued actively in the Pacific Northwest since the mid-1950's. However, increasing timber and land values have spurred increasing interest in converting brush and hardwoods to conifers. High quality sites command first priority but usually present problems of greatest difficulty. Resprouting shrubs, fast-growing hardwoods, and conifer-damaging animals combine to impede conversion attempts. Existing conversion techniques involve combinations of harvesting, scarifying, slashing, burning, herbicide spraying, animal control, and artificial regeneration. These techniques vary in effectiveness and intensiveness. No technique is a panacea, but all can succeed under given circumstances. Assessment of current practices and the situations to which they best apply are therefore urgent needs.

A survey was conducted during the summer of 1975 to evaluate economic aspects of hardwood management and brushland conversion. This paper summarizes results of that survey as they pertain to various conversion practices and their relative success in the Oregon-Washington Coast Ranges and Washington Cascade foothills.

Procedures

We obtained data in two ways: (1) by interviewing cooperating land management organizations, and (2) by examining selected conversion projects in the field.

Initially, the two-State region previously described was subdivided into eight zones containing high-site brush and hardwood (chiefly red alder (*Alnus rubra*)) reclamation opportunities: Washington Coastal Plain, North Cascade Foothills, Willapa Hills, South Cascade Foothills, Nehalem Hills, Tillamook, Oregon Coastal Plain, and Oregon Coast Range (fig. 1). We selected 16 organizational units, representing eight industrial timber ownerships and three public land management agencies. These cooperators agreed to provide general information on brushland management for their holdings and detailed data on specific reclamation projects. Organizational units were evenly distributed (eight each) between

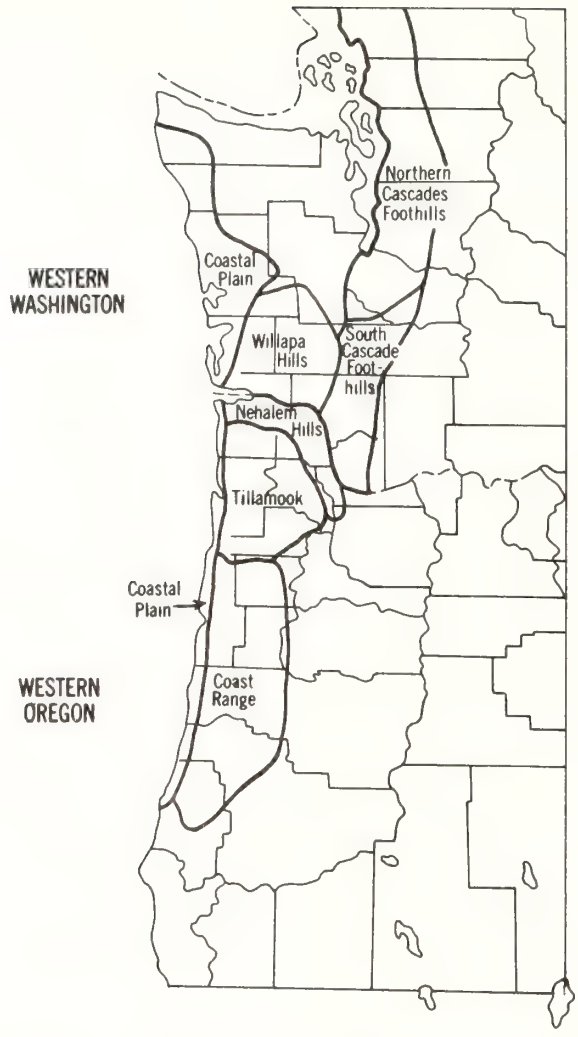

Figure 1.--High-site brush and hardwood reclamation zones surveyed in western Washington and Oregon.

Washington and Oregon. Cooperators were selected on the basis of geographic area and demonstrated experience and familiarity with various conversion practices. Though the ownership sample was not random, it should provide a fairly representative picture of brush conversion and hardwood management practices as they now exist throughout the designated reclamation zones.

Conversion techniques employed by each organizational unit were grouped into six categories by total area treated to date:

1. *Harvest only* -- removal of merchantable overstory with only incidental site preparation and slash disposal.

2. *Tractor scarify* -- partial or complete disruption of slash and shrub residues remaining after harvest; or crushing and uprooting of shrubs and unmerchantable hardwoods without harvest; residues usually windrowed, burned, or both.

3. *Multiple spray* -- application of one or more herbicidal sprays to young hardwoods and tall brush immediately before and after planting large conifer stock.

4. *Slash and burn* -- felling all live and dead hardwoods; understory shrubs usually desiccated with herbicides and broadcast burned by mass ignition.

5. *Spray and burn* -- herbicidal treatment of standing unmerchantable hardwoods and brush, without slashing, followed by broadcast burning; most often applied in low brush shortly after harvesting merchantable overstory.

6. *High-lead scarify* -- crushing and uprooting brush and unmerchantable hardwoods by cable yarding with heavy weights.

Nearly all techniques were accompanied by hand planting--sometimes supplemented by seeding. Relatively few managers relied on artificial seeding as the sole regeneration method. Where two or more conversion techniques overlapped, the one deemed to have had the greatest impact was used to categorize the method.

Projects of "average" effectiveness were selected to avoid sampling either outstanding successes or failures. Projects initiated before 1957 or after 1971 were generally excluded to avoid those too old to provide relevant data or too recent to provide a fair measure of their effectiveness. Each conversion method was sampled approximately in proportion to the commonness of its use within a given organizational unit. Occasional departures from this last guideline were made to favor selection of projects employing more recent technology.

For each conversion project sampled, we recorded the per-acre costs and dates of occurrence for all stand establishment activities and silvicultural treatments from the start of the conversion to the end of the regeneration period. Costs came from actual records, but sometimes only estimates were available. We included costs associated with release spraying but excluded those such as precommercial thinning and fertilizing which are aimed at stand culture rather than stand establishment. We adjusted each cost by a factor derived from the U.S. Gross National Product deflator--with 1975 chosen as the base year for comparison.

In the field, each project was described by general features of size, aspect, slope, site, overstory, and understory. Understories were assigned to one of four plant community classifications that might reflect relationships between plant communities and conversion success. Classifications were: (1) sword-fern (*Polystichum munitum*), (2) salmonberry (*Rubus spectabilis*), (3) vine maple (*Acer circinatum*), and (4) salal (*Gaultheria shallon*). Projects ranged from 18 to 762 acres, and several types of understory were commonly present on any given site. Assignment of a single classification to each project was therefore judgmental and necessarily subjective.

Conversion success was determined by regeneration surveys to assess the distribution, composition, age, height, and number of established conifers. A transect of 25 sampling points provided stocking and density estimates for each project regardless of its size. Estimates of stocking (in percent) were by the stocked-quadrat method based on 100 1/250th-acre plots per project; estimates of density (in trees/acre) by the distance method based on 25 sampling points per project.

Transect lines were systematically spaced throughout each project area to generate average estimates from a wide range of conditions. At each sampling point, four 1/250th-acre plots were laid out as four sectors of a 14.9-foot radius circle. On each sector, the tallest established conifer, its species, age from seed, and estimated height were noted. Only trees at least 3 years old were considered established. In addition, the distance from each sampling point to the closest established conifer was measured to the nearest 1/10th foot.

Results and Discussion

MANAGEMENT PROGRESS AND OBJECTIVES

Organizations sampled own or manage over 6.1 million acres of forest land in the brush and hardwood reclamation zones previously described (table 1). Of this area, 60 percent lies in Washington and 40 percent in Oregon; 38 percent is under State and Federal management and 62 percent in industrial holdings.

About 14 percent, or 867 thousand acres, of this collective ownership are dominated by brush and hardwoods, mostly suitable for conversion to conifers. Within the confines of this sample, Washington contains slightly more potentially convertible lands (55 percent) than Oregon (45 percent). Public and private conversion opportunities are split about equally (52 percent versus 48 percent).

Of the above acreage, 87 percent is classed as hardwood (i.e., containing over 30 percent stocking in hardwood species). The balance (13 percent) consists chiefly of brush with a negligible component of hardwoods.

HARDWOOD CONVERSION

Substantial progress in converting brush and hardwoods has already been made. To date, nearly 216 thousand acres on the ownerships sampled have been converted. Most lands reclaimed previously are now satisfactorily stocked with conifers. The bulk (84 percent) lie in Washington and probably reflect logging histories and ownership patterns that generally differ from Oregon. The ratio of private to public lands converted--84 and 16 percent, respectively--also suggests somewhat differing management objectives between the two classes of ownerships.

Tractor scarification has been the dominant conversion technique used in both States for both private and public ownerships. Nearly 120 thousand acres, or 55 percent of the sampled conversion area, were treated by this method. Harvesting with little or no site preparation accounted for 23 percent of the acreage in older conversions and was normally applied in mature hardwood stands where problems with slash and brush were minimal. More recently developed methods are less well represented. Lands converted by these methods include: multiple spray, 9 percent; spray and burn, 7 percent; slash and burn, 5 percent; and high-lead scarification, 1 percent.

Of the 757 thousand acres now classed as predominantly supporting hardwoods, 665 thousand acres (88 percent) are planned for eventual conversion to conifers by their managers. Based on the 16-unit sample, hardwood acreage remaining to be converted on public lands exceeds that on private holdings. Also, conversion opportunities remaining in Washington somewhat exceed those in Oregon. If areas

Table 1--*Area summary of high-site brush and hardwood lands as either converted or not yet converted to conifers by 16 ownership units in western Washington and Oregon*

(In acres)

Ownership	Owned	Brush and hardwood	Brush	Hardwood	Converted							Hardwood not yet converted			
					Total	Harvest	Tractor scarify	Multi-ple spray	Slash and burn	Spray and burn	High-lead scarify	To be converted	Retained in hardwoods	Retained and managed for harvest	Retained and not managed for harvest
Oregon:															
Public 1	330,000	25,500	10,200	15,300	3,135	20	875	2,240	--	--	--	9,180	6,120	4,285	1,835
Public 2	400,000	45,000	4,500	40,500	1,750	750	1,000	--	--	--	--	22,275	18,225	9,110	9,115
Public 3	619,760	155,000	--	155,000	4,550	--	350	850	--	3,350	--	150,350	4,650	--	4,650
Private 1	645,000	87,000	10,000	77,000	13,750	3,500	10,250	--	--	--	--	57,750	19,250	16,360	2,890
Private 2	88,285	16,605	2,490	14,115	610	--	610	--	--	--	--	9,880	4,235	3,390	845
Private 3	126,000	40,000	8,000	32,000	4,850	500	2,000	--	350	1,500	500	28,800	3,200	3,040	160
Private 4	44,000	8,000	800	7,200	660	--	30	600	30	--	--	4,320	2,880	2,305	575
Private 5	213,000	9,700	485	9,215	4,490	700	590	3,200	--	--	--	8,755	460	--	460
Total	2,466,045	386,805	36,475	350,330	33,795	5,470	15,705	6,890	380	4,850	500	291,310	59,020	38,490	20,530
Washington:															
Public 4	1,000,000	222,000	33,300	188,700	24,200	--	14,200	2,000	--	8,000	--	179,265	9,435	--	9,435
Private 6	370,000	38,000	13,300	24,700	4,115	400	3,715	--	--	--	--	20,995	3,705	3,705	--
Private 7	372,655	60,225	24,090	36,135	38,000	10,000	25,000	2,400	--	--	600	32,520	3,615	1,810	1,805
Private 8	240,000	20,000	--	20,000	10,040	--	6,000	40	3,000	1,000	--	18,000	2,000	1,000	1,000
Private 9	335,000	4,500	450	4,050	21,200	4,000	17,000	100	100	--	--	3,850	200	--	200
Private 10	457,300	40,500	2,025	38,475	24,310	7,445	13,965	2,200	700	--	--	30,780	7,695	6,155	1,540
Private 11	481,460	60,300	--	60,300	42,085	12,880	20,075	2,000	6,730	400	--	57,285	3,015	1,810	1,205
Private 12	399,000	34,500	--	34,500	17,990	9,660	4,300	3,640	390	--	--	30,700	3,800	3,800	--
Total	3,655,415	480,025	73,165	406,860	181,940	44,385	104,255	12,380	10,920	9,400	600	373,395	33,465	18,280	15,185
Total	6,121,460	866,830	109,640	757,190	215,735	49,855	119,960	19,270	11,300	14,250	1,100	664,705	92,485	56,770	35,715
Public	2,349,760	447,500	48,000	399,500	33,635	770	16,425	5,090	--	11,350	--	361,070	38,430	13,395	25,035
Private	3,771,700	419,330	61,640	357,690	182,100	49,085	103,535	14,180	11,300	2,900	1,100	303,635	54,055	43,375	10,680

surveyed, however, are adjusted for the disproportionate land base represented in Oregon and Washington, conversion opportunities between the two States are probably about equal.

HARDWOOD MANAGEMENT

Retention of hardwood types is currently anticipated for over 92 thousand acres or 12 percent of the lands thus classified. Sixty-one percent of this acreage is to undergo some form of timber harvest with no attempt at type conversion. No timber harvesting is planned for the 36 thousand-acre balance chiefly retained as buffer strips for stream protection. Managers indicated legal, esthetic, and economic reasons for not converting these riparian sites to conifers.

By percentage of respondents, the following factors were cited in descending order of frequency as reasons for maintaining hardwood cover types: (1) sites unsuited to conifers (94 percent), (2) State water quality regulations (75 percent), (3) esthetic or recreational considerations (56 percent), (4) unfavorable financial analysis (44 percent), and (5) other reasons that included insufficient funding and manpower, amelioration of root rot problems, and preservation of wildlife habitat and hardwood supply (31 percent).

A generally low intensity of management is anticipated for the 57 thousand acres of hardwood types retained for sustained harvest. Simply waiting for natural hardwood regeneration after harvest is the commonest regeneration policy. A less frequently followed policy encourages natural hardwood regeneration with minimal site preparation. Only one respondent indicated a general policy of harvesting, site preparation, black cottonwood (*Populus trichocarpa*) planting, and thinning. Limited cottonwood planting was also anticipated by two other respondents, but not as a matter of general policy. Mean planned rotation length among all ownerships managing hardwood lands for a sustained yield of hardwood products (chiefly red alder) was 45 years.

CONIFER MANAGEMENT

In contrast to hardwood management policies, a generally high intensity of management is planned for conifer stands already converted from hardwoods and brushfields as well as for the two-thirds million acres scheduled for future conversion (table 2). Planting following site preparation is the almost universally preferred regeneration strategy. Only 19 percent of organizations contacted planned to conduct any artificial seeding on converted lands, and then only at minimal levels to supplement planting.

Although Douglas-fir remains the species of choice for conifer plantations, western hemlock and other conifers will be increasingly used by forest managers. Only 3 of 16 organizational units contacted plan to rely entirely on Douglas-fir. The balance anticipate planting at least 5 percent hemlock and other conifers. One fourth of all managers will use at least 20 percent hemlock and other conifers in their conversion programs, and one large owner will plant 75 percent hemlock.

A trend toward use of large planting stock in conversion projects is also nearly universal. Only 31 percent of the managers contacted planned to use any small, bare-root stock, and even those managers will use more large stock than small. Containerized planting stock will assume increasing importance, especially among those managers planning to regenerate with western hemlock and conifers

Table 2--*Regeneration and management strategies planned by 16 ownership units for converting high-site brush and hardwood lands to conifers in western Washington and Oregon*

Ownership	Species of planting stock			Class of planting stock			Age for precommercial thinning	Ages for commercial thinning	Rotation length	Frequency for fertilizer application
	Douglas-fir	Western hemlock	Other	Large bare root	Small bare root	Containerized				
	Percent						Year			Number
Oregon:										
Public 1	100	--	--	100	--	--	20	--	70	0
Public 2	100	--	--	100	--	--	15	45	80	0
Public 3	95	3	2	100	--	--	15	25	65	0
Private 1	75	20	5	10	--	90	15	35,45	50	5
Private 2	100	--	--	75	25	--	15	30,40	60	2
Private 3	95	5	--	75	24	1	11	25,35	50	0
Private 4	95	5	--	50	45	5	8	25	55	1
Private 5	100	--	--	100	--	--	12	30	45	3
Washington:										
Public 4	90	5	5	50	45	5	15	30,40,50	60	3
Private 6	25	75	--	25	--	75	15	--	50	0
Private 7	95	--	5	100	--	--	15	35,35	50	2
Private 8	90	10	--	90	--	10	--	30,35	45	0
Private 9	98	2	--	100	--	--	12	30	55	8
Private 10	80	15	5	100	--	--	10	30,40	50	8
Private 11	80	15	5	85	--	15	15	30,40	45	6
Private 12	95	3	2	70	25	5	15	30,40	50	7

other than Douglas-fir. Half the sampled ownerships plan to use at least some container-grown stock, and two organizational units currently favor its use over bare-root seedlings.

All but one organization plan to thin converted stands precommercially at 8-20 years, most usually at age 15. All but two organizations intend to thin converted stands commercially--usually several times--before final harvest. Most private managers (75 percent) plan to fertilize their converted stands at time of precommercial thinning and at frequent intervals thereafter. Chiefly because of environmental restrictions, public land managers presently contemplate only limited forest fertilization in converted stands. Mean rotation length planned on private lands averages 50 years; on public ownerships just under 70 years.

CONVERSION SUCCESS

To evaluate success of the 6 conversion techniques previously defined, we examined 99 conversion projects. Projects were distributed among 8 designated conversion zones as follows: Washington Coastal Plain (9), Willapa Hills (10), North Cascade Foothills (14), South Cascade Foothills (21), Nehalem Hills (9), Tillamook (12), Oregon Coastal Plain (3), and Oregon Coast Range (21). Sampling of conversion techniques was roughly in proportion to past use of the method (table 1):

Conversion technique	Proportion of lands converted	Proportion of samples taken
	(Percent)	
Harvest only	23	13
Tractor scarify	55	53
Multiple spray	9	19
Slash and burn	5	6
Spray and burn	7	8
High-lead scarify	1	1

Though complete sampling could not be achieved, 26 out of the 48 possible technique-zone combinations are represented by at least one sample project.

Both stocking and density measures may be used to compare relative success of conversion methods. Greatest reliance should be placed on estimates of stocking based on stocked quadrat surveys (100 plots/project). Density estimates based on measured distance to the nearest established conifer (25 sampling points) are less reliable. Because of the generally clumped tree distribution encountered on many conversion projects, density estimates are probably low in most instances (Batcheler 1971), and particularly so at low stocking levels. Subjective comparisons in the current survey can be based on stocking classes adopted some years ago for 1/250-acre plots (Reynolds et al. 1953). These classes are at least familiar to most foresters and land managers, if not agreed upon by all of them:

Stocking class	Stocking range
	(Percent)
Nonstocked	0 - 9
Poor stocking	10 - 39
Medium stocking	40 - 69
Good stocking	70 - 100

Examples of good success were encountered in all six conversion techniques sampled (table 3). Likewise, successful conversions were examined in all but one of eight reclamation zones. The Oregon Coastal Plain was represented by only three individual projects which are probably not indicative of average success for the zone as a whole. Projects of poor success, on the other hand, were encountered only in association with tractor-scarify and multiple-spray conversions. The only exception was one harvest-only conversion that was marginal between poor and moderate stocking. Although less well represented, slash-and-burn, spray-and-burn, and high-lead-scarify projects were all at least moderately successful and produced good stocking in 11 out of 15 instances.

Conversion success by all methods in terms of stocking obtained was 14 percent greater in Washington than in Oregon. This result reflects generally easier past conversion opportunities in Washington as well as inclusion of conversion projects from the North Cascade Foothills, where problems seem less difficult than those in other zones of either State. The trend was also heavily weighted by the relatively greater success of tractor-scarify conversions in Washington and may not suggest much real difference in ease of future conversion opportunities for either

Table 3--*Conifer stocking and density by conversion zone and technique for 99 projects in western Washington and Oregon*[1/]

Conversion zone	Harvest	Tractor scarify	Multiple spray	Slash and burn	Spray and burn	High-lead scarify
Washington:						
Washington Coastal Plain	67	80	34	86	--	--
	(65-69)	(63-95)	--	--	--	--
	270	366	114	660	--	--
	(2)	(5)	(1)	(1)	--	--
South Cascade Foothills	67	65	38	52	--	71
	(55-79)	(48-95)	(6-69)	--	--	--
	414	279	132	164	--	244
	(2)	(11)	(6)	(1)	--	(1)
North Cascade Foothills	--	78	57	86	86	--
	--	(27-93)	--	(74-93)	--	--
	--	439	170	532	522	--
	--	(9)	(1)	(3)	(1)	--
Willapa Hills	66	82	--	66	--	--
	(60-76)	(65-92)	--	--	--	--
	359	598	--	297	--	--
	(3)	(6)	--	(1)	--	--
Oregon:						
Oregon Coast Ranges	69	62	47	--	73	--
	--	(28-83)	(26-62)	--	(64-89)	--
	366	292	126	--	414	--
	(1)	(6)	(11)	--	(3)	--
Tillamook	46	53	--	--	84	--
	(39-57)	(29-80)	--	--	(77-91)	--
	92	144	--	--	506	--
	(3)	(5)	--	--	(4)	--
Nehalem Hills	58	58	--	--	--	--
	(44-73)	(41-76)	--	--	--	--
	178	163	--	--	--	--
	(2)	(7)	--	--	--	--
Oregon Coastal Plain	--	16	--	--	--	--
	--	(10-22)	--	--	--	--
	--	16	--	--	--	--
	--	(3)	--	-	--	--
All	61	65	44	77	80	71
	(39-79)	(10-95)	(6-69)	(52-93)	(64-91)	--
	265	310	130	453	424	244
	(13)	(52)	(19)	(6)	(8)	(1)

[1/] Within each data group statistics read from top to bottom: mean stocking, stocking range--in parentheses, mean density, and number of projects represented--in parentheses. Stocking is in percent based on 100 1/250th-acre plots; density is in trees/acre based on 25 sampling points.

Oregon or Washington. On the basis of past experience, however, and general impressions formed in this survey, we predict that future hardwood conversions in Oregon will average more difficult and less successful than those in Washington.

Impressions of success for each conversion technique are summarized as follows:

Harvest only. Though the projects examined were moderately successful on the whole, none were outstanding; and most reflected intensive use of supplementary techniques such as release spraying and animal control after planting. In addition,

most new stands were under heavy brush competition that was suppressing growth and reducing survival of conifers. Oregon's Tillamook conversion zone appeared least adaptable for successful use of harvesting with only incidental site preparation.

Tractor scarify. Tractor scarification produced the widest range of results in terms of conifer stocking (10 to 95 percent). This was the most common of all past methods and also the best represented in sampling. Success in Washington was generally high and consistently greater than that in Oregon (74 percent versus 52 percent). Average stocking ranged between 65 and 82 percent for four conversion zones in Washington; between 16 and 62 percent for four zones in Oregon. Stand densities in Washington were also notably higher than in Oregon. More aggressive brush and possibly greater problems with tree-damaging animals in Oregon may account for most of these differences.

Multiple spray. Use of chemical sprays alone without scarification or burning was overall the least successful of techniques sampled. Stocking levels resulting from this practice averaged between poor and medium (40 percent) in Washington, and only slightly better in Oregon (47 percent). Medium stocking, however, was obtained on 14 out of 19 projects for both States combined. A complex of live and dead brush in the understory combined with both live and dead hardwoods in the overstory to produce conditions inimical to planted conifers. Growth and survival of conifer seedlings were hindered by competition for nutrients and moisture, by excessive shading, by physical obstruction of fallen dead materials, and, to some extent, by animal damage.

Slash and burn. Though examples of this technique were not examined in Oregon, its use in Washington was mostly successful. Based on six projects, stocking was medium on two and good to excellent on the remaining four. In one instance, slash and burn was successfully applied to an attempted multiple-spray conversion that had previously failed. The technique requires considerable investment in materials and labor; but it avoids most use of expensive mechanical equipment such as employed in scarification.

Spray and burn. This technique is used shortly after harvest of merchantable hardwoods to reduce complexes of slash and generally low brush. Seven out of eight conversions were located in Oregon, and all were at least moderately successful. Six resulted in good stocking, and two provided high levels of medium stocking. Based on four examples, the technique worked especially well in the Tillamook zone.

High-lead scarify. Only one example of this technique was sampled. Located in Washington's South Cascade Foothills, it provided good stocking of conifers able to compete with developing brush. The method is expensive and will probably require follow-up with herbicide or other treatments to insure survival and maintain dominance of conifers on most areas.

Relationship of conversion success to variables other than the techniques applied was summarized for site index, understory, aspect, and slope.

No consistent trend appeared to be associated with site index. Although more intensive effort was usually devoted to converting higher sites, average stocking was only slightly greater and may well have been offset by generally more difficult conversion opportunities:

Site index	Projects	Mean stocking
	(Number)	(Percent)
130	3	60
140	17	63
150	8	56
160	23	67
170	22	55
180	13	65
190+	13	70

Understory communities dominated by sword-fern and vine maple regenerated less successfully than salmonberry or salal communities. This trend was apparent in both Washington and Oregon and suggests real differences in ease of conversion for different plant communities:

Understory	Projects	Mean stocking
	(Number)	(Percent)
Washington:		
Sword-fern	14	62
Salmonberry	18	77
Vine maple	17	63
Salal	5	77
Oregon:		
Sword-fern	7	54
Salmonberry	27	56
Vine maple	8	51
Salal	3	64
Washington and Oregon:		
Sword-fern	21	59
Salmonberry	45	65
Vine maple	25	59
Salal	8	72

The above differences in conversion success are obviously confounded by other variables of site, technique, and sample size that make their interpretation difficult. Furthermore, no obvious correlation between conversion technique and understory could be detected. Multiple-spray conversions averaged least successful in the sword-fern dominated understory type (table 4).

Though differences were erratic, there are some indications that southerly and westerly aspects were converted more successfully than easterly and northerly aspects:

Aspect	Projects	Mean stocking
	(Number)	(Percent)
N	15	61
NE	4	48
E	6	51
SE	9	70
S	27	60
SW	11	71
W	11	74
NW	6	67
Level or mixed	10	56

Table 4--*Conifer stocking by understory and conversion technique for 99 projects in western Washington and Oregon*[1/]

Understory	Harvest	Tractor scarify	Multiple spray	Slash and burn	Spray and burn	High-lead scarify
Sword-fern	67(2)	68 (8)	37(7)	74(4)	--	--
Salmonberry	60(7)	66(22)	47(7)	91(1)	79(7)	71(1)
Vine maple	58(4)	60(14)	48(5)	74(1)	86(1)	--
Salal	--	72 (8)	--	--	-	--

[1/] Stocking is in percent based on 100 1/250th-acre plots; data in parentheses are number of projects represented.

Although this trend, if real, runs counter to the normally expected tendency for south exposures to provide difficult natural regeneration opportunities (Bever 1954, Lavender et al. 1956), there is at least no indication that such was the case among the conversion projects sampled. Both Shaw (1953) and Stewart (1966) found that south slopes regenerated more successfully than other aspects following artificial seeding. A common association between north slopes and sword-fern communities may also suggest problems in type conversion that differ from those following conventional conifer harvest.

Not unexpectedly, a trend toward a decrease in conversion success was associated with an increase in steepness of slope:

Slope (Percent)	Projects (Number)	Mean stocking (Percent)
0 and 5	22	70
10 and 15	20	69
20 and 25	18	61
30 and 35	16	62
40 and 45	7	57
50 and 55	7	49
60 and 65	5	46
70+	5	46

Marginally good stocking was obtained on level to gentle terrain where more intensive methods, such as tractor scarification, could be applied. Success generally fell to low levels of medium stocking on slopes in excess of 45 percent.

In response to general questions regarding factors that limited regeneration success on specific hardwood conversions, a majority of managers indicated that competing vegetation and animal damage were of prime importance:

Factor	Washington	Oregon	Washington and Oregon
	- - - - - - - (Percent) - - - - - -		
Weather	7	2	5
Competing vegetation	41	67	53
Animal damage	52	58	55
Poor planting stock	7	24	15
Other	6	4	5

A common association between competition and damage factors suggests that densely vegetated sites provided good habitat for damaging animals. Since most conversion techniques probably improve habitat for such animals, the two problems are closely intertwined (Dimock 1974).

CONVERSION COSTS

On some recent projects, not all costs of conifer establishment have yet occurred; and this fact should be considered in interpreting cost data. Since 1972, 27 percent of the sampled projects have been planted or replanted. Hence, many of these conversions will probably require further silvicultural treatment to insure their success. In one extreme case a multiple-spray project has already cost $212 per acre with only 6-percent stocking success resulting. Another $200-$300 per-acre outlay for retreatment over the next few years is anticipated, but not included in our cost data. Some older projects, on the other hand, include all or nearly all expenditures needed for successful stand establishment.

Average total costs per acre ranged from $39 to $505 (table 5). In general, the cost variation within each technique-zone conversion class is so large that few concrete conclusions can be drawn. Mean per-acre costs for each conversion technique suggest that harvest only was least expensive ($103), followed by tractor scarify ($140), multiple spray ($149), slash and burn ($235), and spray and burn ($269). However, in terms of cost per established conifer, both slash-and-burn and spray-and-burn techniques compared favorably with harvest and tractor-scarify methods--despite substantially higher per-acre costs for the former. In contrast, though multiple-spray conversions were only moderately expensive per acre, costs per established conifer were high, averaging over $1. Cost of high-lead scarification ($210), represented by only one sample, was probably low based on our experience.

Mean expenditures for conversion were quite similar between Washington and Oregon ($153 and $155 per acre). Costs for public conversion projects, however, averaged $223 compared to $139 for projects in the private sector. The $84 difference likely reflects costly environmental constraints associated with more recent conversions on public lands, in addition to possible selection bias and probable sampling error. In summary, an average conversion cost of $154 per acre suggests that brushland reclamation is seldom cheap. Moreover, since actual tree planting costs averaged only about half the total conversion outlay ($78), the continuing need for intensive and improved site preparation treatments seems abundantly clear in high-site hardwood conversion.

Table 5--*Conversion costs by zone and technique expressed in 1975 dollars per acre for 99 projects in western Washington and Oregon*[1/]

Conversion zone	Harvest	Tractor scarify	Multiple spray	Slash and burn	Spray and burn	High-lead scarify
Washington:						
Washington Coastal Plain	96	101	133	254	--	--
	(89-102)	(54-204)	--	--	--	--
	0.35	0.26	1.17	0.38	--	--
	(2)	(5)	(1)	(1)	--	--
South Cascade Foothills	102	132	158	170	--	210
	(58-174)	(45-275)	(117-212)	--	--	--
	0.24	0.47	1.20	1.04	--	0.86
	(2)	(11)	(6)	(1)	--	(1)
North Cascade Foothills	--	153	153	229	176	--
	--	(122-173)	--	(183-257)	--	--
	--	0.34	0.90	0.43	0.34	--
	--	(9)	(1)	(3)	(1)	--
Willapa Hills	150	174	--	300	--	--
	(66-197)	(70-291)	--	--	--	--
	0.42	0.29	--	1.01	--	--
	(3)	(6)	--	(1)	--	--
Oregon:						
Oregon Coast Range	148	185	145	--	330	--
	--	(94-282)	(39-351)	--	(193-505)	--
	0.40	0.63	1.15	--	0.80	--
	(1)	(6)	(11)	--	(3)	--
Tillamook	65	184	--	--	246	--
	(41-89)	(77-487)	--	--	(135-389)	--
	0.70	1.28	--	--	0.49	--
	(3)	(5)	--	--	(4)	--
Nehalem Hills	78	73	--	--	--	--
	(75-81)	(63-91)	--	--	--	--
	0.43	0.45	--	--	--	--
	(2)	(7)	--	--	--	--
Oregon Coastal Plain	--	112	--	--	--	--
	--	(97-120)	--	--	--	--
	--	7.17	--	--	--	--
	--	(3)	--	--	--	--
All	103	140	149	235	269	210
	(41-197)	(45-487)	(39-351)	(170-300)	(135-505)	--
	0.39	0.45	1.15	0.52	0.57	0.86
	(13)	(52)	(19)	(6)	(8)	(1)

[1/] Within each data group, statistics read from top to bottom: mean cost, cost range--in parentheses, cost per established conifer, and number of projects represented--in parentheses.

Conclusions

More than 100,000 acres of brush and 3/4 million acres of brush-hardwood mixtures--almost all potentially convertible to conifers--presently occur on over 6.1 million acres of forest lands sampled in this survey. If one assumes that these lands typify forest ownerships in the Coast Ranges and western Cascade Range foothills of Washington and Oregon, the task of converting high-site brush and hardwoods to more valuable conifers for the above region as a whole will exceed by 3 times the management projections summarized here. Much has been done already. Over 200,000 acres on the ownerships surveyed have now been reclaimed. However, more than 3 times that amount are scheduled for future conversion from hardwoods to conifers.

To date, managers have concentrated their reclamation efforts on the easiest and most accessible conversion opportunities. Generally more difficult and remote opportunities remain. Not all conversion techniques proven in the past to be successful on gentle terrain will be adaptable to steep ground. Hence, there is an urgent need not only to refine existing methods but also to devise new ones. As at present, various techniques will be required to fit different circumstances; and no single method will foreseeably apply to all or even most conditions. Improved guidelines for prescribing techniques that provide the best balance between success and cost in given situations are also needed.

The harvest-only method lends itself less readily to current conditions than any other method examined. Unless market conditions and utilization standards for hardwoods (chiefly red alder) improve quite radically, this situation is likely to persist. The technique is often effective only when accompanied by intensive, supplemental measures such as spraying, burning, and animal control. Moreover, it has immediate application only to hardwood stands of harvestable age. In past practice, the harvest-only method was most applicable to the easiest conversion opportunities that presented little slash-disposal or brush-threat problems.

Tractor scarification will continue to be useful on gentle ground with slopes not exceeding 30 percent. Less terrain of this kind will be available in future conversion opportunities, and use of tractor scarification will be increasingly limited. Tractors used in "yo-yo" fashion--one tractor lowering another downslope, then back up with its winch--can extend this method to steeper slopes, but the technique is expensive (Gratkowski et al. 1973) and results in site degradation. Likewise, scarification by high-lead techniques remains quite costly, but may have good possibilities for future use if efficiency can be improved. All scarification projects observed in this survey showed that partial scarification was generally less successful than more complete mechanical disruption for attaining good conifer stocking within a short space of time.

Multiple-spray conversion techniques generally fell short of providing desired levels of conifer stocking. Only 3 out of 19 projects examined yielded even high levels of medium stocking (60-69 percent). These results suggest that additional refinements of this method are needed to improve its success and consistency on high sites. Possibly development of more effective and broader spectrum herbicides will help to achieve better conifer stocking. Methods developed to reduce the complex of live and dead brush even further than normally possible with sprays alone are probably needed to provide a favorable seedling environment.

Combinations of chemicals and fire, as in slash-and-burn and spray-and-burn techniques, were most consistently successful in achieving conversion with high levels of conifer stocking. These methods tentatively appear to have best potential for both future application and further refinement. Nevertheless, environmental constraints may limit opportunities for their use. Hence, if viable options are to remain open to forest managers for converting low-value brush/hardwood stands to highly productive coniferous forests, continuing technological advances will be vital.

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USDA Forest Service Research Paper PNW-214
1976

GOVT DOCUMENTS

EFFECTS OF THE DOUGLAS-FIR TUSSOCK MOTH NUCLEOPOLYHEDROSIS VIRUS (BACULOVIRUS) ON THREE SPECIES OF SALMONID FISH

G.M. Banowetz
J.L. Fryer
P.J. Iwai
M.E. Martignoni

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AUTHORS:

G. M. Banowetz and J. L. Fryer are with the Department of Microbiology, Oregon State University, Corvallis.

P. J. Iwai and M. E. Martignoni are with the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Corvallis, Oregon.

EFFECTS OF THE DOUGLAS-FIR TUSSOCK MOTH NUCLEOPOLYHEDROSIS VIRUS (BACULOVIRUS) *ON THREE SPECIES OF SALMONID FISH*

Reference Abstract

Banowetz, G. M., J. L. Fryer, P. J. Iwai, and M. E. Martignoni. 1976. Effects of the Douglas-fir tussock moth nucleopolyhedrosis virus (*Baculovirus*) on three species of salmonid fish. USDA For. Serv. Res. Pap. PNW-214, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead trout (*Salmo gairdneri*) showed no pathology when exposed to *Baculovirus* by three different routes. Cell lines derived from chinook salmon and steelhead trout were refractory to nonoccluded virions, and no cytopathology was observed by light and electron microscopy. Both polyhedra and nonoccluded virions were inactivated rapidly by coho salmon exposed to the virus by three different routes.

KEYWORDS: Virus (insect) (-salmonids, nucleopolyhedrosis, *Baculovirus*, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

RESEARCH SUMMARY

Research Paper PNW-214

1976

This study examined whether the use of a nucleopolyhedrosis virus from *Orgyia pseudotsugata* for control of Douglas-fir tussock moth infestations would be harmful to certain salmonid fish residing in waters adjacent to the affected forests.

The virus caused no pathology in two salmonid cell lines or in three species of salmonid fish. Furthermore, the virus survived less than 24 hours in coho salmon exposed to the agent by the waterborne route, feeding, or injection. It also appeared that coho salmon might not eat *O. pseudotsugata* larvae when other food was available.

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Introduction

Douglas-fir tussock moth (*Orgyia pseudotsugata*) infestations of forests in western North America have caused severe economic losses to the forest industry (Wickman et al. 1973). As recently as 1973, an outbreak occurred in northeast Oregon and southeast Washington which affected nearly 500,000 acres and resulted in extensive defoliation of economically important species of fir trees. In the past, chemical pesticides were used to control moth outbreaks; however, due to certain problems associated with the use of these pesticides, other control measures became desirable.

Two nucleopolyhedrosis viruses belonging to subgroup A of the genus *Baculovirus* have been isolated from *O. pseudotsugata* (Hughes and Addison 1970). Both viruses occur naturally and are major factors in terminating moth infestations. One of these, designated BV (bundle virus), is characterized by bundles of nucleocapsids common to a single envelope. This virus has been registered by the U.S. Environmental Protection Agency for use as a biological control agent against the larvae (Registration No. 27586-1, August 11, 1976). The information presented here was needed to demonstrate safety of the viral agent for fish.

This study investigated the effects of BV on economically important species of salmonid fishes which may reside in waters within forest areas subject to tussock moth infestation. Experiments were conducted to observe whether the virus affected either live fish or fish cell lines and to determine if BV persisted in the animals when introduced by three different routes.

Materials and Methods

VIRUS PREPARATIONS

A suspension of nonoccluded virions was prepared as follows: hemolymph from 25 larvae (average weight 300 mg), inoculated per os with pure BV inclusion bodies 5 days prior to the bleeding, was collected into a sterile conical centrifuge tube in an ice bath (Martignoni and Scallion 1961). Sufficient tissue culture medium was added such that the hemolymph was diluted 1:40. Hereafter, the tissue culture medium (Auto-Pow, Flow Laboratories, Inc.)[1/] supplemented with streptomycin (100 µg/ml), penicillin (100 IU/ml), and 10 percent fetal bovine serum will be referred to as MEM-10 percent. The hemolymph suspension was then passed through a 0.45-µm filter and stored at 4 °C. A 1:1000 dilution of this preparation was used for all the in vivo experiments requiring nonoccluded virions.

A second suspension of BV virions was prepared and used for the in vitro experiments with cell lines. This preparation was diluted 1:10 with MEM-10 percent and stored at 4 °C.

A commercial preparation of BV polyhedra (Nutrilite 1973, Lot 1), was used for in vivo experiments requiring the occluded virions. This also was stored at 4 °C.

INSECTS

Inbred strain GL *Orgyia pseudotsugata* larvae were used throughout this study. These animals were fed an artificial diet and maintained at 22 °C in 100- x 15-mm disposable petri dishes. Second-instar, 75-mg and 300-mg larvae were used for specific tests in this investigation.

SALMONID CELL LINES

Two salmonid cell lines were employed in this study. They were CHSE-214, derived from chinook salmon (*Oncorhynchus tshawytscha*) embryos, and STE-137, derived from steelhead trout (*Salmo gairdneri*) embryos (Fryer et al. 1965).

1/ Trade names used should not be construed as endorsement by Department of Agriculture.

The cells were maintained at 18 °C in MEM-10 percent throughout this study. At the time of these experiments, the CHSE-214 cells had been subcultured 225 times and the STE-137 cells 159 times.

FISH

Chinook salmon fingerlings (average weight 0.5 g) were obtained from the Leaburg Trout Hatchery (Oregon Department of Fish and Wildlife). Coho salmon (*O. kisutch*) fingerlings (average weight 0.5 g) and smolts (average weight 20 g) were supplied by the Alsea Salmon Hatchery (Oregon Department of Fish and Wildlife). Steelhead trout were obtained from the Nehalem River Salmon Hatchery (Oregon Department of Fish and Wildlife).

All fish were maintained in constantly flowing 13 °C well water at the Oregon State University Fish Disease Laboratory and fed Oregon Moist Pellets. The well water at this laboratory contained no fish pathogens.

BIOASSAY PROCEDURES

Intrahemocoelic injection of 75-mg larvae was used to detect and quantitate nonoccluded BV virions. Larvae were anesthetized with ether, disinfected in 0.4 percent Hyamine, and injected in the second proleg with 5.0 µl of virus suspension. A calibrated Agla micrometer syringe (Burroughs Wellcome Co.) fitted with a Tomac 0.25-ml tuberculin syringe and disposable 30-gage 13-mm needle (B-D Yale) was used for all injections. The injected larvae were maintained at 30 °C for 8 days after the inoculation. All dead larvae were examined microscopically for polyhedra in the tracheal matrix near the midgut. Larvae with polyhedra in this region were recorded as deaths attributable to BV.

A peroral bioassay involving addition of virus to the surface of the ration[2/] was used to detect and quantitate BV polyhedra. Disposable analyzer cups (2 ml) were filled to the 1-ml level with warm diet, then allowed to airdry for 1-2 hours (h). Each cup then received 20 µl of the virus-containing suspension so that the entire diet surface was wetted. After the diet surface had dried, a second-instar larva was placed in each cup, a cap perforated for air exchange was positioned, and the cups were incubated at 30 °C for 12 days. Only larvae which had molted to the second instar within 18 h before the test were used. Dead larvae were examined for polyhedra as described above.

When quantitation of BV activity was desired, replicate groups of 20 larvae were used for each of the bioassay procedures. If the test was employed only to detect the presence of BV, one group of 20 larvae was used for each sample. The mortality data from intrahemocoelic assays were evaluated by means of logit chi-square analysis (Berkson 1953). We used the LOCSAN program by R. L. Giese, Purdue University. LD50 determined by intrahemocoelic injection are designated IH-LD50.

EXPOSURE OF FISH CELL LINES TO BACULOVIRUS

Cell cultures (CHSE-214 and STE-137) were propagated at 18 °C in 32-ounce prescription bottles to 80-90 percent monolayer before being exposed to BV. At that point, the medium was removed from the cells and replaced with MEM-10 percent which contained BV nonoccluded virions (9.90×10^5 IH-LD50 units/ml). After 24-h exposure to the virus, the medium was again removed from the bottles. A portion of the cells was used for electron microscopic examination while the remainder was subcultured. The virus-containing medium was bioassayed after it was removed from the cell lines. Cells exposed to virus were transferred through five successive generations

[2/] Iwai, Paul J., and Mauro E. Martignoni. 1976. Peroral bioassay of activity of *Baculovirus* of *Orgyia pseudotsugata*: Exposure by diet-surface treatment (DST). 11 p. Unpublished laboratory procedure on file at the Forestry Sciences Laboratory, Corvallis, Oregon.

at 7- to 10-day intervals and examined by light microscopy for any pathological changes.

Cells to be examined by electron microscopy were fixed with 2.5 percent glutaraldehyde in Sørensen's phosphate buffer at pH 7.0 followed by 1 percent osmium tetroxide. The samples were dehydrated in acetone and embedded in an Epon-Araldite mixture. Preparative work and electron microscopy were done by A. H. Soeldner, Department of Botany and Plant Pathology, Oregon State University. The samples were examined with a Phillips 300 electron microscope at a magnification of 30,000.

EXPOSURE OF SALMONID FINGERLINGS TO BACULOVIRUS

The animals used for these experiments were of a size and age considered most likely to show any virus-induced pathologies. These fish were exposed to BV by three different routes; a waterborne exposure, intraperitoneal (ip) injection, and by feeding.

The waterborne exposure was conducted as follows: 200 animals were placed in 4 gallons of aerated water which was constantly agitated with a magnetic stirring bar. Sufficient polyhedra were added to the water to give an effective dose of 100-surface-acre doses of virus, adjusted to the surface area of the container employed. After 18-h exposure, the animals were transferred to 13 ^{o}C water and maintained and observed there for 30 days. At that time, a representative sample of fish was placed in Bouin's fixative and submitted to Dr. R. Stroud, Department of Veterinary Science, Oregon State University, for histopathological examination.

Fish were injected with BV nonoccluded virions in the following manner: the animals were anesthetized, then injected ip with 20 µl of a suspension which contained 1.67×10^2 IH-LD50 units of BV virus. The fish were maintained in 13 ^{o}C water for 30 days. At that time a sample of animals was submitted for histopathological examination.

The 200 animals exposed by the oral route were fed polyhedra incorporated into their food at a rate equivalent to 100-acre doses adjusted to the surface area of the tanks. The fish consumed this amount of food within a period of 24 h. After 30 days had elapsed, a sample of these fish was submitted for histopathological examination.

Coho salmon, chinook salmon, and steelhead trout were exposed to BV by each route described above. Control animals of each species were also maintained in 13 ^{o}C well water and submitted for histopathological examination at the same time the exposed animals were collected.

SURVIVAL OF BACULOVIRUS *IN COHO SALMON SMOLTS*

The purpose of these experiments was to determine whether BV persisted in the fish and, if so, in which organ(s) it resided. Smolts were chosen for this work because their size allowed examination of individual internal organs. These animals also were exposed to the virus by the waterborne route, ip injection, and the oral route. Each experiment was done with triplicate groups of fish.

The procedure used for the waterborne exposure was identical to that described for fingerlings except that only 15 animals were held in the virus-containing water. The water was bioassayed for polyhedra at the start of the experiment and after the 18-h exposure period. With time 0 defined as the end of the 18-h exposure period, fish were sampled at time 0, 12, 24, 48, and 96 h. At each sampling time, three fish were sacrificed. The pooled kidneys, livers, and spleens from each sample group were weighed, diluted 1:10 with MEM-10 percent, ground in a Virtis tissue grinder, and assayed for polyhedra. Pooled intestines from these fish were treated identically.

Fish which received ip injections of BV nonoccluded virions were anesthetized and then injected with 0.1 ml of a suspension containing 8.33 x 10^2 tussock moth IH-LD50 units. Sampling began 8 h later with additional samples at 24, 48, and 96 h. At each sampling time, three fish were sacrificed. Kidneys and spleens were removed and pooled. A separate sample of liver tissues was treated identically. Each sample was weighed, diluted 1:10 with MEM-10 percent, ground in a Virtis tissue grinder, centrifuged at 1000 g for 15 minutes, and passed through a 0.45-mm filter. The samples then were assayed for the presence of BV.

Initially, the oral route exposure was to be via infected larvae. The salmon (even when starved up to 5 days) would not eat larvae. Even larvae coated with 10 percent bovine serum albumin to induce sinking were refused. Thus, these smolts received an oral exposure to BV by the addition of polyhedra to their food. As with the fingerlings, the equivalent of 100-surface-acre doses, adjusted to the surface area of the tanks, were fed within a period of 24 h. After the fish were fed the polyhedra, they were sampled at time 0, 4, 8, 24, and 48 h. Sampling was done in the following manner: at each sampling time, three animals were sacrificed and their digestive tracts were removed and pooled. The tissue was weighed, diluted 1:10 with MEM-10 percent, and homogenized in a Virtis tissue grinder. The resulting homogenate was then assayed for the presence of polyhedra.

Results

EFFECT OF BACULOVIRUS *ON SALMONID CELL LINES*

No pathological changes were observed in either cell line (CHSE-214 and STE-137) exposed to BV virions. The cells exposed to the virus appeared identical to control cells when examined by either light or electron microscopy. No change occurred in the growth rate of the cells or in their response to subculture. K. Hughes (Forestry Sciences Laboratory, Corvallis, Oregon) also examined the grids prepared for electron microscopy and saw no evidence that the virus had entered into or altered the cells.

EFFECT OF BACULOVIRUS *ON SALMONID FINGERLINGS*

Coho salmon, chinook salmon, and steelhead trout fingerlings were not adversely affected by exposure to BV by a any of the three routes. The exposed animals appeared healthy and showed growth similar to the control fish through the period of the experiment. No histopathology attributable to BV was observed in any of the exposed animals, and no virus was recovered from fish sampled 30 days after exposure to BV.

SURVIVAL OF BACULOVIRUS *IN COHO SALMON SMOLTS*

Both polyhedra and BV virions were inactivated rapidly by the salmon (table 1). Within 24 h after the exposure period, the virus was inactivated regardless of the route of exposure. The animals were particularly refractory to polyhedra added to the water supply.

In addition to the insusceptibility of the fish to this virus, it also appeared that fish would not likely eat *O. pseudotsuga* larvae. Three groups of fish, deprived of food for 5 days prior to the experiment rejected larvae while they did not reject earthworms cut to the same size as the larvae.

Discussion

This study indicates that the use of BV as an agent to control *O. pseudotsugata* infestations should have no deleterious effects on chinook salmon, coho salmon, or steelhead trout which reside in waters adjacent to treated forests. Coho salmon seem reluctant to eat *O. pseudotsugata*

Table 1--*Survival of a Douglas-fir tussock moth* (Orgyia pseudotsugata) *nucleopolyhedrosis virus* (Baculovirus) *in coho salmon* (Oncorhynchus kisutch) *smolts when administered by three different routes*

Exposure route	Organ(s) sampled	Virus recovery at postexposure times			
		8 h	24 h	48 h	96 h
Intraperitoneal[a] injection	Kidney, spleen	+[d]	--	--	--
	Liver	+[d]	--	--	--
Waterborne[b]	Kidney, liver, spleen	-[d]	--	--	--
	Digestive tract	-[e]	--	--	--
Oral[c]	Digestive tract	+[e]	--	--	--

[a]Salmon were injected with 8.33 x 10^2 *O. pseudotsugata* larvae IH-LD50 units of nonoccluded virions.

[b]The equivalent of 100 surface acre doses (10^{13} polyhedra/acre), adjusted to the surface area of fish tank, were added to the water and fish exposed for 18 h.

[c]The equivalent of 100 surface acre doses (10^{13} polyhedra/acre), adjusted to the surface area of fish tank, were fed within a period of 24 h.

[d]Virus recovery by intrahemocoelic injection in 75 mg *O. pseudotsugata* larvae.

[e]Virus recovery by peroral exposure of second-instar *O. pseudotsugata* larvae.

larvae. The virus does not persist in these fish.

Other investigations have shown nucleopolyhedrosis viruses have no pathological effect on mammalian cell lines (McIntosh and Maramorosch 1973, Ignoffo and Rafajko 1972). Himeno el al. (1967) found that DNA from a nucleopolyhedrosis virus from silkworms was infective in certain mammalian cell lines, but they did not demonstrate infectivity with the intact virion or polyhedra. McIntosh and Shamy (1975) reported that a nucleopolyhedrosis virus from *Autographa californica* became associated with a reptilian cell line, and that certain viral proteins were synthesized by the inoculated cells. They did not observe complete viral replication and no cytopathology was reported.

Wolf (1975) described experiments in which certain amphibian and fish cell lines were exposed to nucleopolyhedrosis viral agents from *O. pseudotsugata*. No cytopathology was found in any of the cell lines tested.

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Banowetz, G. M., J. L. Fryer, P. J. Iwai, and M. E. Martignoni.
1976. Effects of the Douglas-fir tussock moth nucleopolyhedrosis virus (*Baculovirus*) on three species of salmonid fish. USDA For. Serv. Res. Pap. PNW-214, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead trout (*Salmo gairdneri*) showed no pathology when exposed to *Baculovirus* by three different routes. Cell lines derived from chinook salmon and steelhead trout were refractive to nonoccluded virions, and no cytopathology was observed by light and electron microscopy. Both polyhedra and nonoccluded virions were inactivated rapidly by coho salmon exposed to the virus by three different routes.

KEYWORDS: Virus (insect) (-salmonids, nucleopolyhedrosis, *Baculovirus*, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

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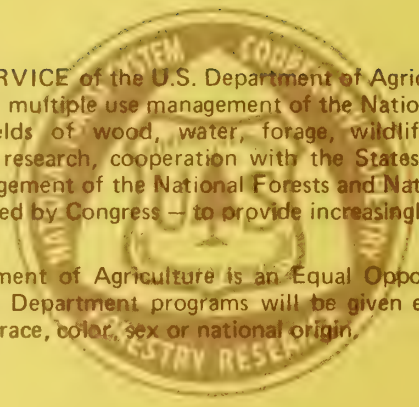

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development program

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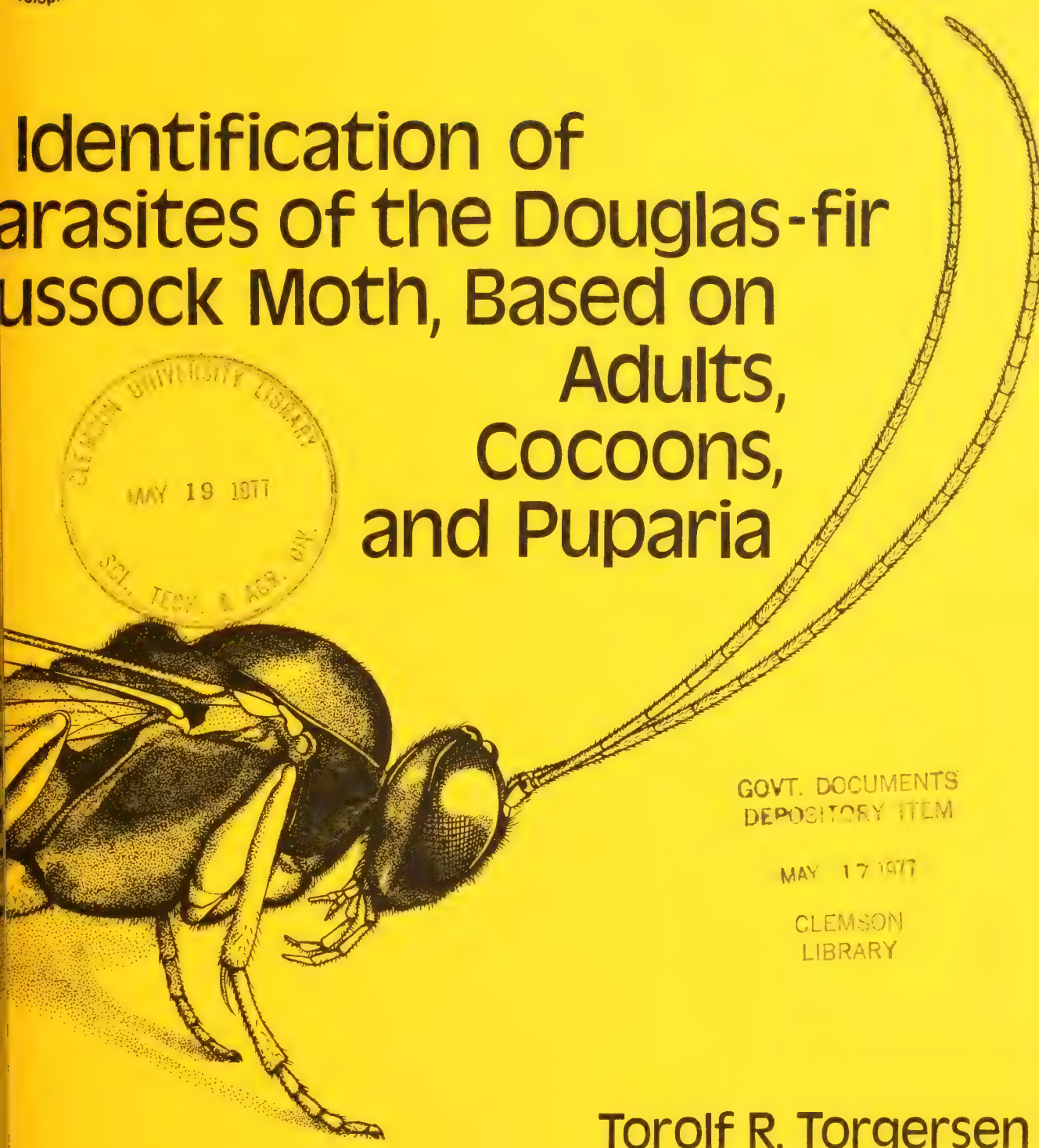

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PORTLAND, OREGON

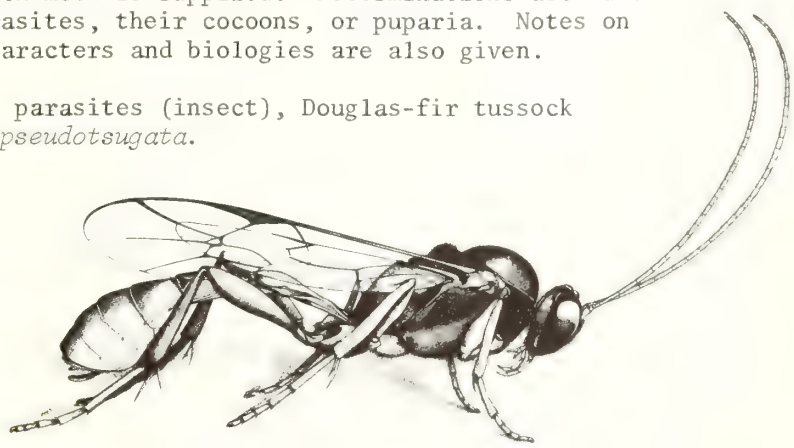
Identification of Parasites of the Douglas-fir Tussock Moth Based on Adults, Cocoons, and Puparia

Reference Abstract

Torgersen, Torolf R.
1977. Identification of parasites of the Douglas-fir tussock moth based on adults, cocoons, and puparia. USDA For. Serv. Res. Pap. PNW-215, 28 p., illus. Pacific Northwest Forest and Range Experimental Station, Portland, Oregon.

A key for the identification of egg, larval, and pupal parasites of the Douglas-fir tussock moth is supplied. Determinations are based on features of adult parasites, their cocoons, or puparia. Notes on additional diagnostic characters and biologies are also given.

KEYWORDS: Parasite key, parasites (insect), Douglas-fir tussock moth, *Orgyia pseudotsugata*.



RESEARCH SUMMARY

Research Paper PNW-215

1977

Since the widespread outbreaks of Douglas-fir tussock moth in the West during the early 1970's, many pest management and university personnel have become involved in rearing this insect. Rearings have been conducted for a variety of purposes, among them the determination of the occurrence of parasitism and the species comprising the parasite complex.

An illustrated key to 30 species of the more common parasites is presented. The key permits identification of both adult parasites and their cocoons or puparia. Supplemental diagnostic descriptions are given to help the user verify determinations. Brief notes on the biology of each species are also included.

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The research reported here was financed in whole or part by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program.

Introduction

With increased interest in the Douglas-fir tussock moth, mainly since 1972, both State and Federal agencies have become involved in rearing this insect for a variety of reasons. Reared material has been used to determine the incidence of disease, to evaluate the effectiveness of spray formulations in tests and operational projects, and to determine the occurrence of parasites. In the latter case, the parasite complex was either treated as a group, or the specimens were sent to specialists for determination.[1/] Obtaining determinations is a time-consuming process, and workers still face the task of comparing the determined specimens with the series of specimens which were not seen by the specialist. This can be a tedious and confusing process when the worker is unfamiliar with the characters used for separating different taxonomic groups.

The following illustrated key and descriptive notes are designed to provide a means for identifying most of the parasites that have been recorded from the tussock moth. Species that have been collected only once or have been collected in a limited geographic area and are rare or uncommon even at that location have been omitted. Notes on morphology and coloration are included so the user can verify his determinations by checking additional characters not included in the key.

Terminology is from Borror and Delong (1960), Townes (1969), and Marsh (1971). The terms "petiole" and "first abdominal segment" are synonymous; petiole is used in the key to reduce wordiness. To facilitate viewing wing venation and number of tarsal segments, it may be advantageous to backlight these structures rather than to shine a light directly on them.

Key to Douglas-fir Tussock Moth Parasite Adults, Their Cocoons, and Puparia

1. Parasite from egg or egg mass 2
   Parasite or cocoon from host larva, pupa, or unknown host stage 4

2. Minute (0.3-0.6 mm), yellow-bodied; abdomen broadly joined to thorax; tarsi 3-segmented; postmarginal vein lacking (fig. 1) . . . . . 24. *Trichogramma minutum*

   Small (1.0-1.6 mm), black- or yellow-bodied; abdomen constricted where it joins thorax; tarsi 4- or 5-segmented; postmarginal vein (pmv) present (figs. 2, 3) 3

3. Black-bodied (1.0-1.2 mm) with 5-segmented tarsi; flagellum of antenna with 10 or 11 segments; compound eyes dark, nearly black; submarginal vein (sm) and marginal vein (mv) continuous (fig. 2). . . . . 26. *Telenomus californicus*

[1/] Insect Identification and Beneficial Insect Introduction Institute, ARS-USDA Agricultural Research Center - West, Systematic Entomology Laboratory, Beltsville, MD 20705.

Black- (♀) or yellow-bodied (♂) (1.4-1.6 mm), with 4-segmented tarsi; flagellum 5- or 6-segmented; scape of male much inflated; compound eyes and ocelli red; submarginal vein (sm) and marginal vein (mv) interrupted (fig. 3). . . . . 25. *Tetrastichus* sp.

4. Parasite cocoon(s) or puparium (figs. 34, 39, 43-50) 5
Parasite adult 16

5. Dipterous puparium (figs. 34, 39). 6
Hymenopterous cocoon(s) (figs. 43-50). 8

6. Posterior end of puparium with a craterlike cavity; stigmal plates absent (figs. 35, 36). . . . . 1. *Agria housei*
Posterior end of puparium without a craterlike cavity; two stigmal plates present (figs. 40-43) 7

7. Stigmal plates elevated; about as high as protuberance below plates (figs. 39, 40); stigmal slits not on pronounced ridges (fig. 41). . . . . 2. *Carcelia yalensis*
Stigmal plates not elevated; much lower than protuberance; stigmal slits each on a distinct ridge (fig. 42) . . . . . 3. *Exorista mella*

8. Cocoon free of substrate[2/] or host remains (fig. 43), or attached to substrate by a strand of silk arising from end of cocoon (fig. 44); solitary 9
Cocoon(s) attached to substrate or host remains (figs. 45-50); solitary or gregarious. 11

9. Cocoon an attenuated ellipse (1.7 x 4.6 to 1.9 x 4.7 mm); tan; composed of loosely spun strands, and usually with a long terminal strand (fig. 44) . . . . . 22. *Meteorus tersus*
Cocoon ovoid or capsulate (2.6 x 4.8 to 4.6 x 7.3 mm); dark brown to nearly black; sometimes with lighter medial band; composed of tightly spun strands, and without a terminal strand (fig. 43). 10

10. Cocoon ovoid (3.0 x 4.7 to 4.6 x 7.3 mm), sometimes with a medial light band (figs. 43a, 43b) . . . . . 16. *Phobocampe pallipes*
Cocoon capsulate (2.6 x 4.8 to 3.2 x 5.7 mm), without a medial light band (fig. 43c) . . . . . 17. *Phobocampe* n. sp.

11. Cocoon capsulate (approx. 3.5 x 6.5 mm), white, gray, or tan, and usually with host larval skin covering or attached to cocoon (figs. 45, 46) 12
Cocoon ellipsoid, or smaller, or otherwise without the above combination of characters (figs. 47-50) 13

12. Cocoon (3.6 x 6.8 to 4.2 x 7.5 mm) white; host larval skin covering most of cocoon dorsally (figs. 45c, 46). . . . . 18. *Hyposoter fugitivus pacificus*
Cocoon (2.2 x 5.2 to 3.6 x 7.1 mm) tan to gray, and usually mottled with dark brown or black; host larval skin not

---

[2/] Substrate, as used here, can mean: foliage, twig, or rearing container, e.g., petri dish, vial, etc.

covering most of cocoon, usually attached at only one point
covering a small area of cocoon (figs. 45a, 45b) . . . . . .
. . . . . 19. *Hyposoter* n. sp.

13. Large, elongate cocoon 3 to 4 times as long as wide (2.6 x 11.3 to 4.0 x 12.0 mm); gray-brown or tan (figs. 47, 48) 14
Smaller, ellipsoid cocoon 2 or 2.5 times as long as wide (1.5 x 4.0 mm); solitary, nearly white cocoon (fig. 49), or gregarious tan cocoons (fig. 50). 15

14. Gray-brown cocoon (approx. 4.0 x 12.0 mm) composed of loose mass of strands over a darker, more dense layer (fig. 47); gregarious or solitary. . . . . 11. *Gambrus canadensis burkei*
Tan cocoon (approx. 3.0 x 12.0 mm) of more densely spun fibers; cocoons commonly formed in a bundle (fig. 48); usually gregarious . . . . . 9. *Iseropus stercorator orgyiae*

15. Nearly white, ellipsoid cocoon (1.5 to 1.9 x 3.6 to 5.6 mm) with a halo of loosely spun silk strands (fig. 49); solitary; not attached to host remains . . . . . 21. *Apanteles* spp.
Tan cocoons with indistinct individual shapes (fig. 50); gregarious; attached to, or closely associated with host larval remains . . . . . 23. *Bracon xanthonotus*

16. Diptera; one pair of wings 17
Hymenoptera; two pairs of wings 19

17. Arista (ar) with setae on basal half; third antennal segment (3d) about twice as long as wide (fig. 29). . . . . 1. *Agria housei*
Arista bare; third antennal segment 2-1/2 or more times as long as wide 18

18. Sternopleuron (stp) (fig. 38) with two prominent bristles; face along inner eye margins silver-gray. . . . 2. *Carcelia yalensis*
Sternopleuron with three prominent bristles; face along inner eye margins yellow or bronze . . . . . 3. *Exorista mella*

19. Forewing without closed cells (figs. 1-6); antenna elbowed, with less than 15 segments. Chalcidoidea and Scelionidae 20
Forewing with two or more closed cells (figs. 7-14); antenna filiform and with more than 15 segments. Braconidae and Ichneumonidae 26

20. Minute (0.3 to 0.6 mm), yellow-bodied; abdomen broadly joined to thorax; tarsi 3-segmented; postmarginal vein absent; wing setae arranged in rows (fig. 1). . . . 24. *Trichogramma minutum*
Small (1.0 mm or longer) dark, yellow, or metallic colored; abdomen constricted where it joins thorax; tarsi 4- or 5-segmented; postmarginal vein (pmv) present; wing setae not arranged in rows (figs. 2-6) 21

21. Tarsi 4-segmented; submarginal vein (sm) and marginal vein (mv) interrupted (fig. 3) . . . . . 25. *Tetrastichus* spp.
Tarsi 5-segmented; submarginal vein (sm) and marginal vein (mv) continuous (figs. 2, 4-6). 22

22. Black-bodied, very small (1.0 to 1.2 mm); stigmal vein (stv) nearly half as long as submarginal vein (sm) and marginal vein (mv) combined (fig. 2); posterior corner of pronotum reaching the tegula . . . . . 26. *Telenomus californicus*
Black, yellow, or metallic; larger (1.4 mm or more); stigmal vein (stv) much shorter than marginal vein (mv) alone (figs. 3-6); posterior corner of pronotum not reaching the tegula. 23

23. Hind femur much enlarged and with a row of teeth along ventral surface; tibia curved (fig. 24) . . . 30. *Brachymeria ovata ovata*
Hind femur not, or only slightly enlarged, and without a row of teeth beneath; tibia nearly straight 24

24. Hind femur with a prominent spine beneath (fig. 25); hind coxa much enlarged and flattened; stigmal area (sta) of wing infused with brown (fig. 4). . . . 29. *Monodontomerus saltuosus*
Hind femur lacking a spine beneath; hind coxa not abnormally enlarged; wing lacking brown in stigmal area (figs. 5-6). . . 25

25. Postmarginal vein (pmv) longer than stigmal vein (stv) and stigma (st) combined (fig. 5). . . . . 27. *Hypopteromalus percussor*
Postmarginal vein about equal in length to stigmal vein and stigma combined (fig. 6). . . . . 28. *Dibrachys cavus*

26. Forewing with one recurrent vein (rv); cubitus (cu) present, forming discoidal (DCL) and cubital (CBL) cells (figs. 7-9); Braconidae. 27
Forewing with two recurrent veins (rv); cubitus absent leaving a single discocubital cell (DCB) (figs. 10-14); Ichneumonidae 29

27. Radius (r) and areolet (AR) present (figs. 7, 8). 28
Radius and areolet absent (fig. 9). . . . . 21. *Apanteles* spp.

28. Petiole about as long as its posterior width; hindwing nervellus (nv) occurring near base of wing, short and curved (fig. 15); forewing as in figure 7. . . . . 23. *Bracon xanthonotus*
Petiole about twice as long as posterior width; hindwing nervellus (nv) occurring about 1/4 of wing length from base, nearly straight (fig. 16); forewing as in figure 8 . . . . . 22. *Meteorus tersus*

29. Petiole about as long as greatest width posteriorly; with spiracle placed ahead of, or near midlength 30
Petiole much longer than greatest width; with spiracle placed behind midlength 36

30. Body yellowish-brown or honey-colored; tarsal claws large, each with a specialized long seta extending from base to claw tip (fig. 30) . . . . . 8. *Theronia atalantae fulvescens*
Body mostly black with some white markings; tarsal claws simple or with a large basal tooth, without specialized seta as above 31

31. Hind femur and tibia reddish-brown. 32
Hind femur reddish-brown; tibia patterned with black and white 33

32. Inner margin of compound eye sharply concave opposite antennal base (fig. 22). . . . . 4. *Itoplectis viduata*
Inner margin of compound eye nearly straight opposite antennal base (fig. 23). . . . . 6. *Coccygomimus sanguinipes erythropus*

33. Hind tibia with extreme base black (fig. 26); mesopleural suture (mps) nearly straight, without an angulation near midlength; propodeal spiracle (pps) elongate (fig. 32). . . . 34
Hind tibia with extreme base white or light colored (figs. 27, 28); mesopleural suture (mps) with an angulation near midlength; propodeal spiracle (pps) round (fig. 33) 35

34. Ovipositor tip curved downward (fig. 31); face of female with pale line along inner margin of eye; face of male mostly white . . . . . 7. *Ephialtes componotus*
Ovipositor tip straight; face of both sexes black . . . . . 5. *Itoplectis quadricingulatus*

35. Nervellus (nv) intersected by discoidella (dsc) below the middle (fig. 17); hind tibia with submedial pale band interrupted by a dark ventral stripe (fig. 27); ovipositor about as long as abdomen; face and clypeus of male black. . . . . 10. *Scambus* spp.
Nervellus intersected by discoidella above the middle (fig. 18); hind tibia with an encircling submedial pale band (fig. 28); ovipositor about half as long as abdomen; face and clypeus of male white . . . . . 9. *Iseropus stercorator orgyiae*

36. Large (9 to 14 mm); head, thorax and abdomen black with white markings; all tibiae and face marked with white. . . . . 14. *Orgichneumon calcatorius*
Smaller (4 to 9 mm); variously colored, not as above 37

37. Areolet (AR) joined to radius (r) by the width of a single vein (figs. 10-12) 38
Areolet (AR) broadly joined to radius (r) (fig. 13); or areolet absent (fig. 14) 42

38. Areolet large, its height approximating length of second recurrent vein (2d rv) (fig. 10); body color yellowish brown. . . . . 20. *Mesochorus* sp.
Areolet much smaller, its height less than half the length of second recurrent vein (figs. 11, 12); head and thorax black, abdomen black or reddish brown. 39

39. Head, thorax, and abdomen black. 40
Head and thorax black, abdomen reddish brown or marked with yellow. 41

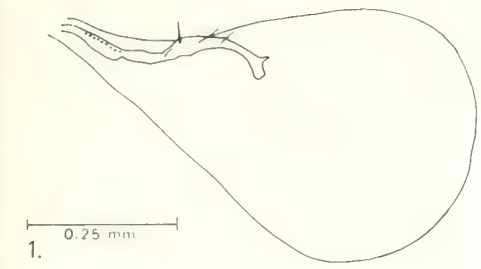
40. Hind coxa and femur reddish brown. . . . . 18. *Hyposoter fugitivus pacificus*
Hind coxa black, femur reddish brown. . . . . 19. *Hyposoter* n. sp.

41. Abdomen reddish brown. . . . . 16. *Phobocampe pallipes*
Abdomen mostly black with yellowish markings on second and third tergites . . . . . 17. *Phobocampe* n. sp.

42. Nervellus intercepted by a discoidella (figs. 20, 21). 43
Nervellus not intercepted by a discoidella (fig. 19); abdominal terga with yellowish markings. . . . . 15. *Bathythrix latifrons*

43. Areolet (AR) broadly joined to radius (r) (fig. 13); nervellus (nv) intercepted by discoidella (dsc) near the middle (fig. 20). . . . . 11. *Gambrus canadensis burkei*
Areolet absent (fig. 14); nervellus intercepted by discoidella well below middle (fig. 21); forewings sometimes banded. . . . 44

44. Forewing with brown bands (fig. 14). . . . . 12. *Gelis tenellus*
Forewing without brown bands, membranes clear. . . . 13. *Gelis* spp.



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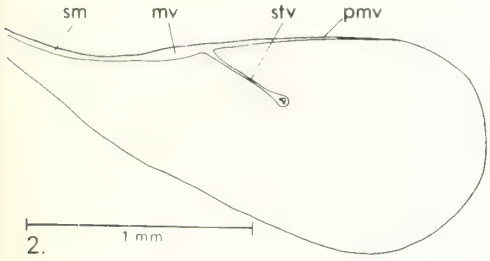

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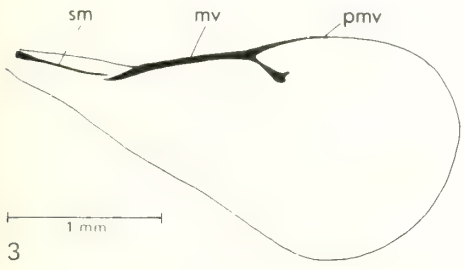

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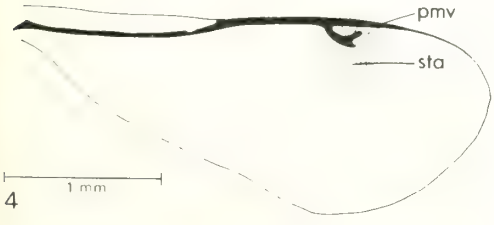

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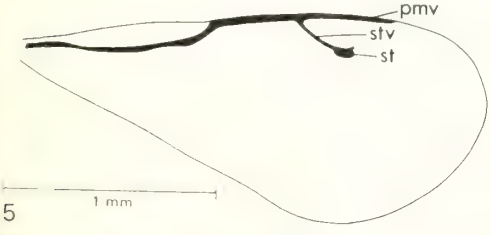

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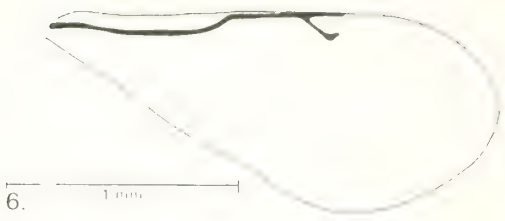

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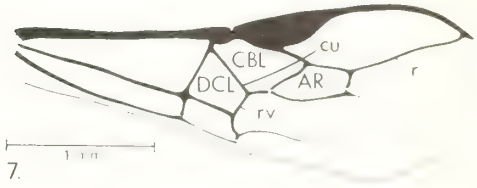

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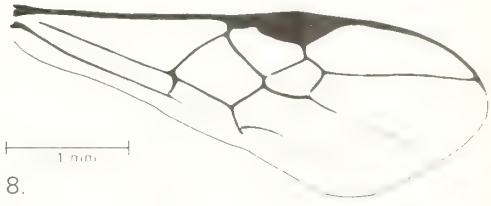

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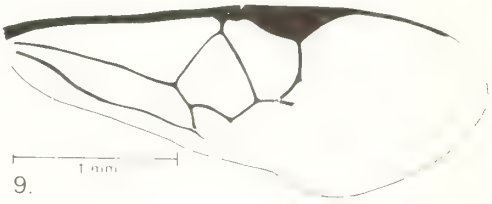

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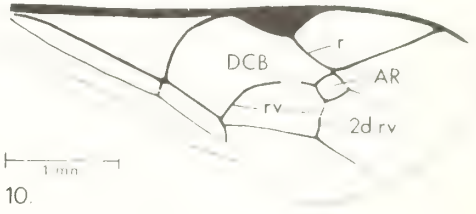
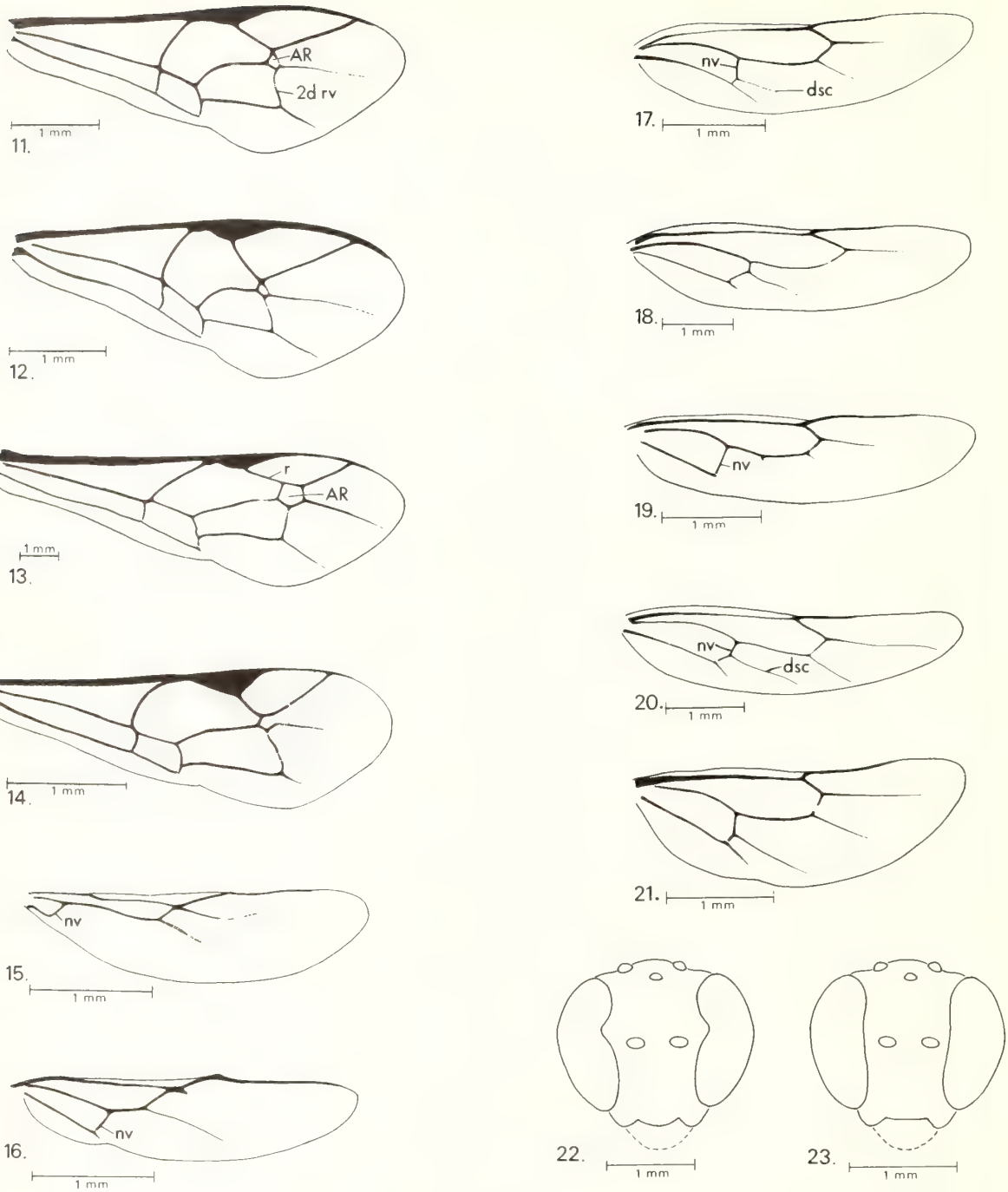
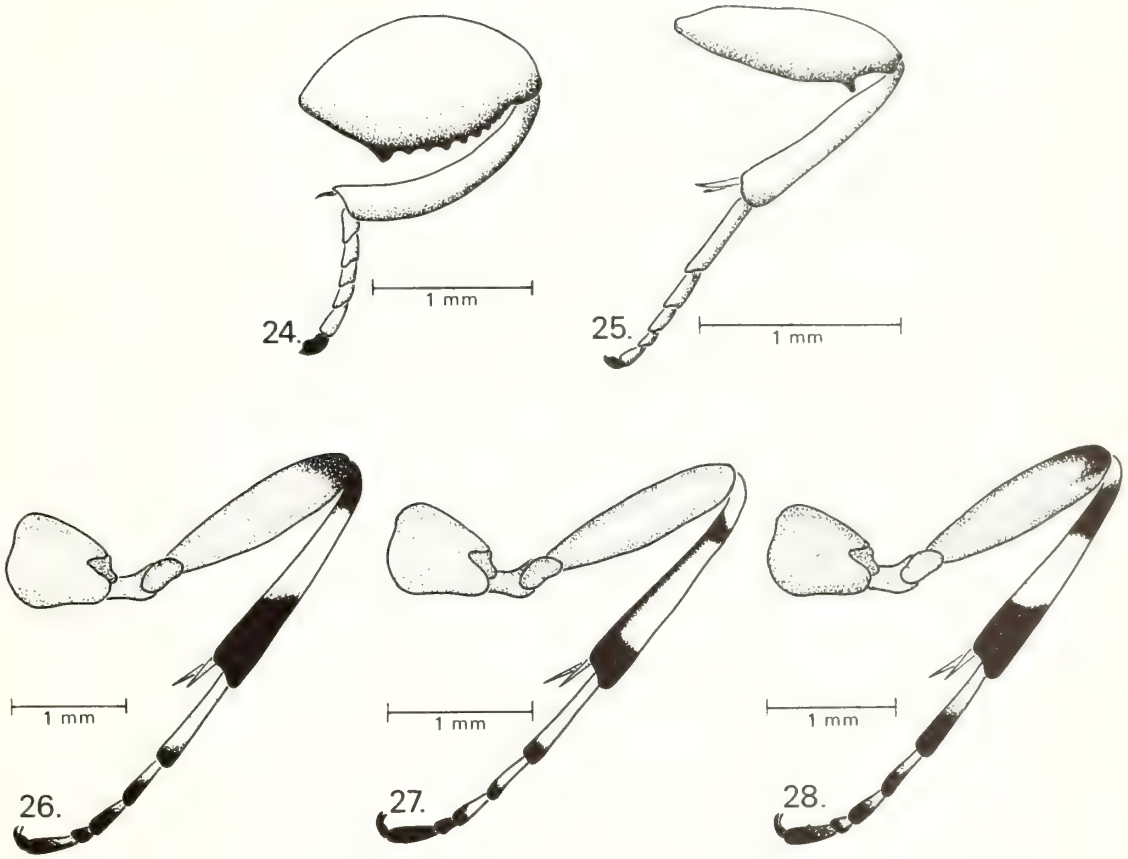


10.

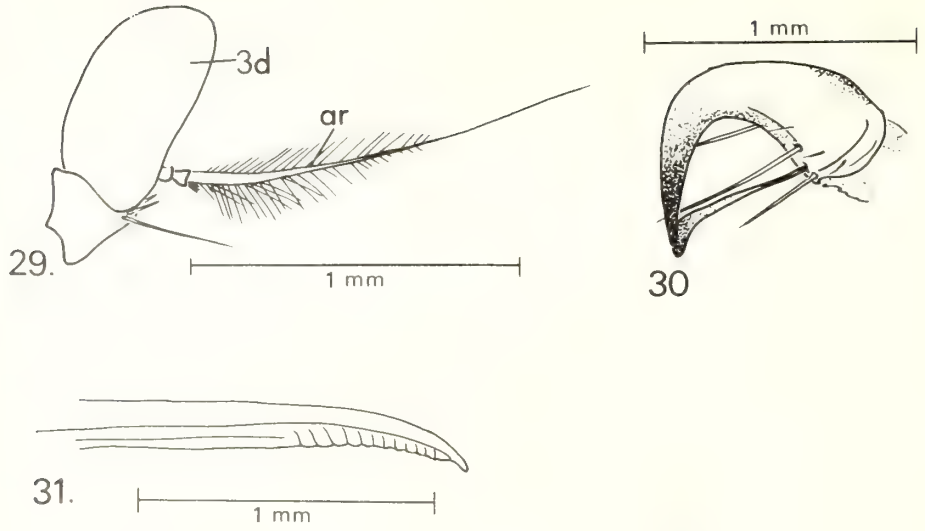
Figures 1-10.--Forewings: 1. Trichogramma minutum; 2. Telenomus californicus; 3. Tetrastichus sp.; 4. Monodontomerus sp.; 5. Hypopteromalus percussor; 6. Dibrachys cavus; 7. Bracon xanthonotus; 8. Meterous tersus; 9. Apanteles sp.; 10. Mesochorus sp. AR, areolet; CBL, cubital cell; cu, cubital vein; DCB, discocubital cell; DCL, discoidal cell; mv, marginal vein; pmv, postmarginal vein; r, radial vein; rv, recurrent vein; 2d rv, second recurrent vein; sm, submarginal vein; st, stigma; sta, stigmal area; stv, stigmal vein.



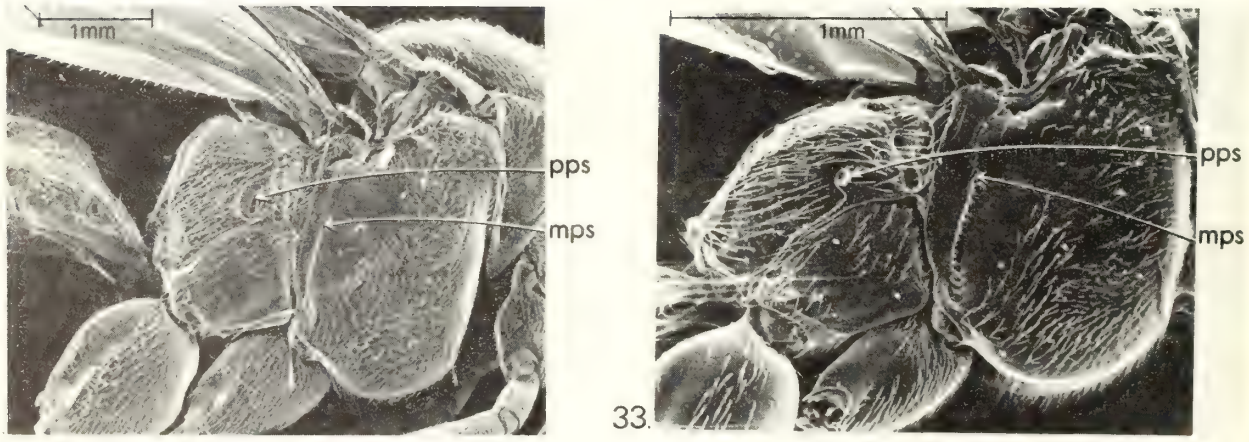
Figures 11-23.--Forewings: 11. Hyposoter fugitivus pacificus; 12. Phobocampe **n. sp.**; *13. Gambrus canadensis; 14. Gelis tenellus.* **Hindwings:** *15. Bracon xanthonotus; 16. Meteorus tersus; 17. Scambus aplopapus; 18. Iseropus stercorator orgyiae; 19. Bathythrix latifrons; 20. Gambrus canadensis burkei; 21. Gelis* **sp.** **Anterior view of heads:** *22. Itoplectis quadricingulatus; 23. Coccygomimus sanguinipes erythropus.* **AR, areolet; dsc, discoidella; nv, nervellus; r, radial vein; 2d rv, second recurrent vein.**



Figures 24-28.--Hind legs: 24. Brachymeria ovata ovata; 25. Monodontomerus sp., 26. Ephialtes componotus; 27. Scambus hispae; 28. Iseropus stercorator.

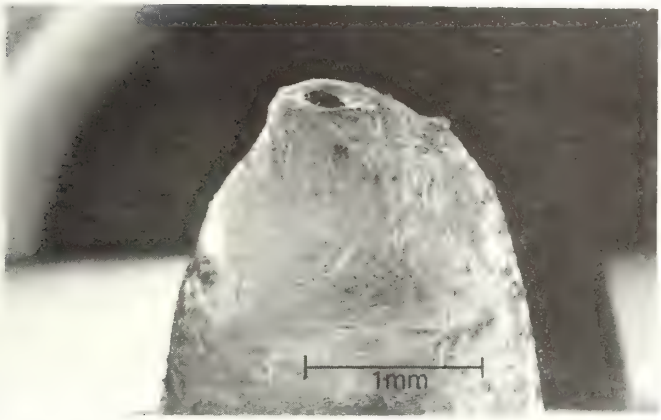


Figures 29-31.--Antenna: 29. Agria housei. Tarsal claw: 30. Theronia atalantae fulvescens. Ovipositor tip: 31. Ephialtes componotus. ar, arista; 3d, third antennal segment.



Figures 32-33.--Mesopleural areas: 32. Ephialtes componotus; 33. Iseropus stercorator orgyiae. mps, mesopleural suture; pps, propodeal spiracle.

34.



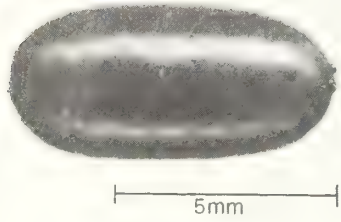
35.

36.

Figures 34-36.--Agria housei: 34. Side view of puparium showing natural exit hole and profile of posterior end; 35. Posterolateral view of puparium showing craterlike cavity; 36. Posterior view of puparium.

37.

38.



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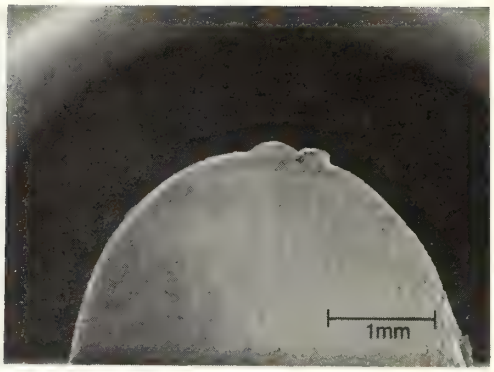

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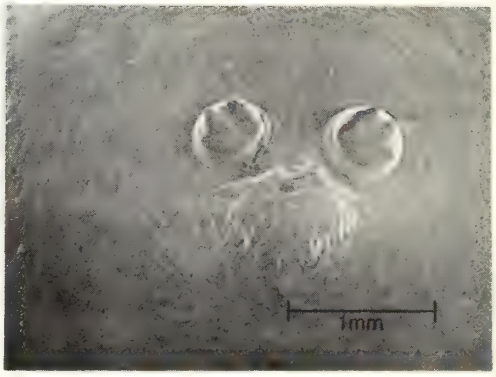
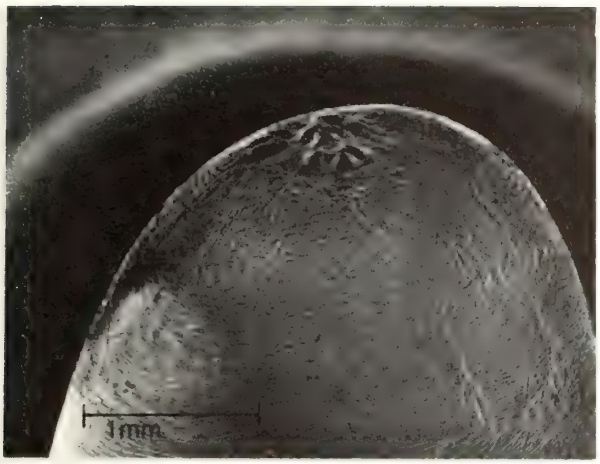


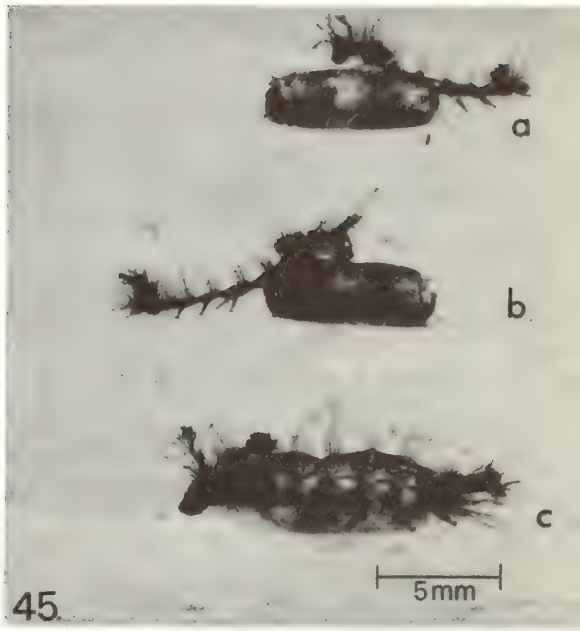
41.

Figures 37-41.--Carcelia yalensis: 37. Side view of adult; 38. Lateroventral view of thorax showing sternopleuron with its two major setae; 39. Side view of unopened puparium; 40. Side view of puparium showing detail of posterior profile; 41. Posterior view of puparium showing detail of spiracular plates. stp, sternopleuron.



42.

Figure 42.--Exorista mella: posterolateral view of puparium showing detail of spiracular plates.

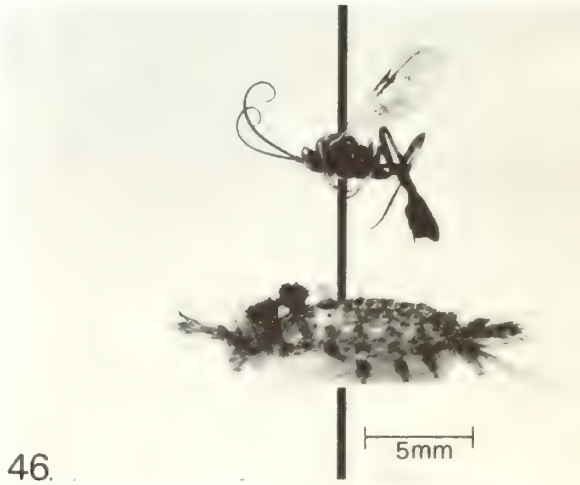


45.

Figure 45.--Cocoons of Hyposoter spp., side view: a. and b. Hyposoter n. sp. c. Hyposoter fugitivus pacificus.

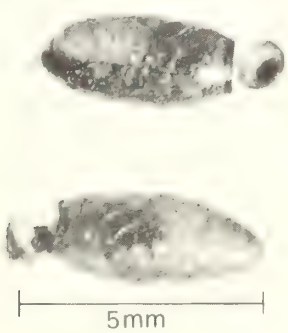
43.

Figure 43.--Cocoons of Phobocampe spp.: a. and b. Phobocampe pallipes; c. Phobocampe n. sp.



46.

Figure 46.--Hyposoter fugitivus pacific adult female and cocoon, side views.



44.

Figure 44.--Meteorus tersus: side view of cocoons showing exit hole and terminal filament.

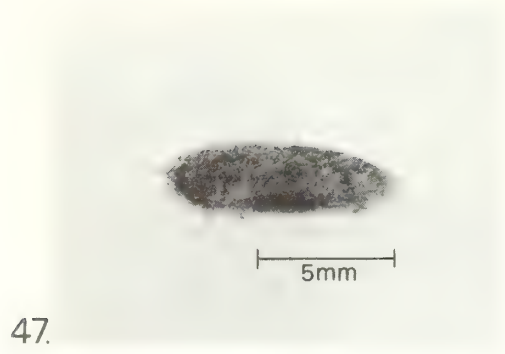


Figure 47.--Gambrus canadensis; cocoon.

Figure 49.--Apanteles sp.; cocoon.

Figure 48.--Iseropus stercorator orgyiae; bundle of several cocoons.

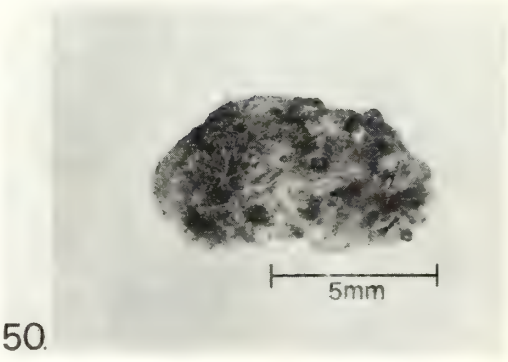


Figure 50.--Bracon xanthonotus; mass of cocoons.

51.

52.

Figures 51-52.--Phobocampe pallipes; larva emerging from host skin.

Additional Diagnostic Features and Notes on Parasites

The following descriptive notes are designed to help the user verify determinations made through the key. In most cases an abbreviated description of the habits of the parasite is also supplied.

DIPTERA

1. *Agria housei* Shewell

(Sarcophagidae)

Figures 29, 34-36

The adult fly is approximately 3.2 to 7.7 mm. Its head, body, and legs are black with gray markings. The predominantly black head has a gena with a distinct gray sheen with changing light angle. The third antennal segment is about half as wide as long; the arista (ar) has setae on basal half or more (fig. 29). There is a poorly developed postscutellum. Posterior margins of the first and second abdominal tergites lack long, prominent setae. Sternopleural area has three prominent setae.

Puparium, 1.9- x 4.8- to 2.6- x 4.7-mm, is reddish brown and slightly darker posteriorly. The main diagnostic character is the prominent craterlike posterior cavity (figs. 34-36). A solitary mature maggot emerges from the late-instar tussock moth larva and drops to the ground. Pupariation and overwintering occur in the duff at a depth of approximately 25 to 40 mm.

2. *Carcelia yalensis* Sellers

(Tachinidae)

Figures 37-41

This fly is approximately 5.0 to 7.9 mm (fig. 37). Its head and body are mostly black with areas of gray and yellowish brown. Gena and frons have a pronounced gray sheen along margin of compound eye; medial area of the frons dark brown. Third antennal segment is 2-1/2 or more times as long as wide; arista bare. Mesoscutellum and lateral areas of the first, second, and third abdominal tergites yellowish brown. There is a well-developed postscutellum. Posterior margins of first, second, and third abdominal tergites each have two or more large prominent setae. Sternopleural area (stp) has two prominent setae (fig. 38). Femora nearly black; tibiae brown to yellowish brown. Tarsal claws much shorter than width of third antennal segment.

Puparium (fig. 39), 3.7- x 6.6- to 4.2- x 7.3-mm, is rich reddish brown to nearly black. Each spiracular plate is borne on a slight protuberance and has three slits (figs. 40, 41).

The host larva is attacked; the mature maggot emerges from the host pupa and drops to the ground where it pupariates and overwinters. In the laboratory, pupariation may take place within the host cocoon near the pupal remains. One or two maggots may successfully develop and emerge from a single host.

Two species of secondary parasites have been reared from *C. yalensis*. A *Pachyneuron*[3/] species was reared from puparia collected in the duff layer in late spring near La Grande, Oregon, in 1974. This pteromalid is a gregarious parasite that emerged from about 10 percent of the puparia collected. Up to two dozen individuals emerged from a single puparium. Another species, *Mastrus argeae* (Vier.),[4/] represented by a single individual, emerged from a puparium in the same collection.

3. *Exorista mella* (Walker)

(Tachinidae)

Figure 42

Adult size is approximately 9.0 to 10.1 mm. The head has a distinct gray sheen; gena and frons bronze; medial area of frons dark brown to black. Third antennal segment is about 2-1/2 times as long as wide; arista bare. Thorax, abdomen, and legs are black with gray markings. Mesoscutellum and lateral area of second abdominal tergite have a brown tinge. There is a well-developed postscutellum. Posterior margins of first, second, and third abdominal tergites each with two or more stout setae. Sternopleural area with three prominent setae. Tarsal claws long and slender; about as long as width of third antennal segment.

Puparium is approximately 4.0 x 7.0 mm. Stigmal plates not raised above surface of puparium; the three slits are each borne on a distinct ridge (fig. 42).

The tussock moth larva is attacked, and the mature maggot emerges from the dead host pupa to pupariate and overwinter in the duff.

HYMENOPTERA

4. *Itoplectis viduata* (Gravenhorst)

(Ichneumonidae: Ephialtinae)

The body may be 6.5 to 12.9 mm; and the ovipositor may add another 2.4 to 4.2 mm to that length. The head, thorax, abdomen, and coxae are black. The black tegula is sometimes pale anteriorly. Legs are mostly dark reddish brown. Ovipositor straight; its tip is not bent downward as in *Ephialtes* species. Inner margin of the compound eye has a rounded notch opposite the antennal base as in figure 22.

According to Dahlsten et al. (1977) this species appears to be capable of ovipositing in prespinning and cocooned larvae as well as pupae. Emergence is from the host pupa.

[3/] Hymenoptera: Pteromalidae.

[4/] Hymenoptera: Ichneumonidae.

5. *Itoplectis quadricingulatus* (Provancher)

(Ichneumonidae: Ephialtinae)

Figure 22

Body length is approximately 5.8 to 8.9 mm; ovipositor 1.5 to 2.0 mm in addition. The head, thorax, and abdomen are black. The black tegula is pale anteriorly. Pro- and mesothoracic legs are mostly reddish to pale. Metathoracic leg with coxa reddish, or sometimes nearly black; femur is reddish. Hind tibia is conspicuously banded with black and white. It is black basally and apically, with an intervening encircling white band. Inner margin of the compound eye has a notch opposite the antennal base (fig. 22).

Host is normally attacked as a pupa within the cocoon and the adult parasite emerges from the host pupa in the spring. There are also two records of *I. quadricingulatus* acting as a secondary parasite emerging from cocoons of *Hyposoter* n. sp.

6. *Coccygomimus sanguinipes erythropus* (Viereck)

(Ichneumonidae: Ephialtinae)

Figure 23

Adults are 7.3 to 11.3 mm in length; the ovipositor is 3.0 to 3.2 mm. The head, thorax, and abdomen are black. The tegula is usually black, but partly pale in males. Legs of female are uniformly reddish brown. Legs of male similar, except that the front coxa may be black. The hind tarsus and apex of the hind tibia are usually black. The inner margin of the compound eye lacks a prominent indentation opposite the antennal base (fig. 23).

Host is normally attacked as a pupa within the cocoon. Emergence from the host pupa occurs in the spring.

7. *Ephialtes componotus* (Davis)

(Ichneumonidae: Ephialtinae)

Figure 31

The body length is approximately 7.4 to 13.9 mm; ovipositor 1.6 to 2.2 mm in addition. The head, thorax, and abdomen are mostly black. Face of the male is largely white; face of the female marked with white along inner margin of the compound eye. The mesonotum is marked with white; tegula white. Coxae, femora, and front and middle tibiae nearly white to light reddish brown. Hind tibia black basally and apically, with an encircling white band near basal third (fig. 26). Ovipositor is about as long as hind tibia and curves downward abruptly near its tip (fig. 31).

Oviposition occurs into the cocooned host pupa within which the developing parasite overwinters; emergence is in the spring.

8. *Theronia atalantae fulvescens* (Cresson)

(Ichneumonidae: Ephialtinae)

Figure 30

Body length is 8.5 to 11.8 mm; ovipositor approximately 2.7 to 3.7 mm. The body and legs are light yellowish brown, with darker markings on mesothorax and metapleurum. Mandibular tips, ovipositor, and ovipositor sheath are dark. Each of the tarsal claws has a specialized long seta extending from base to tip (fig. 30); the arolium is large and conspicuous.

The cocooned host pupa is parasitized, and solitary emergence occurs in the spring.

9. *Iseropus stercorator orgyiae* (Ashmead)

(Ichneumonidae: Pimplinae)

Figures 18, 28, 48

Size is approximately 5.5 to 9.2 mm; ovipositor 2.7 to 3.6 mm. The head, thorax, and abdomen of the female are black; male similar, except that the face, clypeus, and anterior portions of scape and flagellum are white. Tegula and hind corner of pronotum white. Front and middle legs, and hind coxa and femur are nearly white to reddish brown. Hind tibia pale or white basally and near its basal third, and dark or black subbasally and apically. The overall impression is a banded effect of the hind tibia, with the base light colored. Hind tarsal segments are white or pale brown basally; black or nearly so, apically (fig. 28). Nervellus in hind wing is intersected by the discoidella above the middle (fig. 18).

This is a solitary or gregarious, primary parasite which feeds externally in the host's cocoon.

Parasite cocoons may be formed within the host cocoon, but under laboratory conditions the parasite cocoons may be found outside the host cocoon. When several cocoons are present they may be formed side by side in a single mass or bundle of as many as a dozen cocoons (fig. 48). The bundle of cocoons shown measures approximately 10 x 18 mm.

10. *Scambus* spp.

(Ichneumonidae: Ephialtinae)

Figures 17, 27

Adult size is approximately 7 to 13 mm. Head, thorax, and abdomen black, except for the hind corner of the pronotum near the tegula. The anterior surface of the antennal scape and/or the pedicel in the male are pale to nearly white. Hind tibia and tarsus patterned with black and white. The tibia is pale basally and medially, and black apically and subbasally. Most of the hind tarsal segments are pale to white, and dark or black apically (fig. 27). Ovipositor about as long as abdomen. Nervellus in hind wing is intersected by the discoidella slightly or well

below the middle (fig. 17).

The individuals representing this genus all emerged from hosts collected as pupae.

11. *Gambrus canadensis burkei* (Viereck)

(Ichneumonidae: Gelinae)

Figures 13, 20, 47

Size is approximately 6.9 to 9.1 mm. Head, thorax, and base of first abdominal segment black; terminal abdominal segments are dark brown to black. The major portion of first, second, and third abdominal segments and the legs are reddish brown. Ovipositor 2.4 to 2.9 mm; much longer than the depth of the abdomen distally. The ovipositor lacks a dorsal notch near its tip. The forewing (fig. 13) is characterized by a rather large sessile areolet; hindwing as in figure 20.

This species is a solitary or gregarious primary parasite which attacks host larvae and emerges from cocooned ultimate instar larvae or pupae. The parasite cocoons are normally formed within the host cocoon (Dahlsten et al. 1977). Individual parasite cocoons vary in size from 3.8 x 10.6 mm to 4.4 x 13.1 mm. The cocoon is gray brown, with its outer surface composed of loose fibers (fig. 47).

12. *Gelis tenellus* (Say)

(Ichneumonidae: Gelinae)

Figure 14

Body length is approximately 5 mm. The entire insect is reddish brown with darker areas on the propodeum and terminal abdominal segments. The ovipositor is as long, or slightly longer than the hind tibia. The areolet is absent in the forewing, which is conspicuously marked with two dark bands (fig. 14).

This species normally operates as a secondary parasite which attacks and emerges from the cocoon of *Hyposoter* species that parasitize the tussock moth. Although it has not been recorded, it is likely that this species could also attack the cocoons of *Phobocampe* species.

13. *Gelis* spp.

(Ichneumonidae: Gelinae)

Figure 21

Two species of *Gelis*, each represented by a single specimen, have been reared in connection with tussock moth studies. Both species emerged from cocoons of *Phobocampe pallipes*.

The general body color of the two species is black, with reddish brown abdomen and legs.

14. *Orgichneumon calcatorius* (Thunberg)

(Ichneumonidae: Gelinae)

Large (9- to 14-mm) black ichneumonids with prominent white markings on face and/or inner and outer margins of compound eye, the several medial antennal segments of female, pronotum, scutellum, apex of first abdominal segment, tibiae, and on most tarsal segments. Ovipositor very short, not visible, or barely evident at tip of abdomen. Nervellus in hindwing intersected by the discoidella below the middle.

The adult parasite emerges from the host pupa. All the representatives of *O. calcatorius* that I have examined have emerged from hosts collected as pupae in their cocoons. Females of some genera closely related to *Orgichneumon* emerge from their host in the fall and hibernate as adults (Heinrich 1960); this has not been shown for *O. calcatorius*, but it may occur.

15. *Bathythrix latifrons* (Cushman)

(Ichneumonidae: Gelinae)

Figure 19

Body length is about 5 mm; ovipositor about as long as front femur. Head and thorax black; first abdominal tergite dark, nearly black, with yellow on posterior portion. Each of the remaining abdominal terga brown anteriorly, and grading into posterior yellow band of varying width. Front and middle legs pale yellow to light brown. Hind legs darker brown. Hindwing lacks a discoidella intersecting the nervellus (fig. 19).

This is a secondary parasite which oviposits in and ultimately emerges from the cocoon of *Hyposoter* n. sp.

16. *Phobocampe pallipes* (Provancher)

(Ichneumonidae: Porizontinae)

Figures 43a, 43b, 51, 52

This is a medium-sized parasite, about 5.1- to 7.4-mm, with black head and thorax. The mandibles, palps, scape, pedicel, and the tegula are pale yellowish white. The abdomen, legs, and sometimes the distal third of the antennal flagellum are reddish brown. The tarsi bear small pectinate claws, and the short ovipositor, when exserted, has a subapical dorsal notch. In the hindwing the nervellus is not intersected by a discoidella.

This species, a solitary primary internal larval parasite, is one of the most common parasites attacking the tussock moth. After the mature parasite larva has completed its development within the host larva, it emerges from the host (figs. 51, 52) and spins its cocoon. Spinning may occur in close proximity to the host or in the duff on the ground. Ultimately the cocoon falls to the ground where overwintering normally occurs. Cocoons are ovoid, 3.1- x 4.7- to 4.6- x 7.3-mm, usually very dark in color, and commonly have a light circumferential band (figs. 43a, 43b). Newly formed cocoons sometimes move, wiggle, or "jump" when they

are on a firm surface. This is caused by sudden movements of the parasite larva within the cocoon.

17. *Phobocampe* n. sp.

(Ichneumonidae: Porizontinae)

Figure 43c

This species is somewhat smaller than *P. pallipes*, about 4.5 to 5.2 mm. The head, flagellum of antenna, thorax, and most of the abdomen are black. The mandibles, palps, scape, pedicel, tegula, parts of the second and third abdominal tergites, and the lateral portions of the remaining tergites are yellow. The front and middle legs vary from pale yellow to light reddish brown, while the hind leg has a brown or nearly black coxa, a brown femur and distal portion of tibia, and the remainder of tibia and tarsus pale to light brown. The ovipositor is short, usually not extended beyond end of abdomen, and bears a subapical dorsal notch. The tarsi bear small pectinate claws.

This is a very common primary internal larval parasite which emerges from the dead host larva. It forms a capsule-shaped cocoon about 2.6 x 4.8 to 3.2 x 5.7 mm (fig. 43c), which is somewhat smaller than the cocoon of *Phobocampe pallipes* (figs. 43a, 43b). The cocoon is very dark gray brown to nearly black, sometimes having a slight hint of a light band.

18. *Hyposoter fugitivus pacificus* Cushman

(Ichneumonidae: Porizontinae)

Figures 11, 45c, 46

This is a medium-sized species, 5.9- to 7.8-mm, with a very short ovipositor that does not extend much beyond the end of the abdomen (fig. 46). The ovipositor has a subapical dorsal notch. Head, thorax, and abdomen are black. The hind corner of the pronotum near the tegula, and the tegula itself are white. The front and middle legs are light colored to reddish. One of the best diagnostic features separating this species from *Hyposoter* n. sp. is the coloring of the hind leg. In particular, the hind coxa, trochanters, and femur are reddish brown, while the tibia is dark subbasally and apically, and nearly white basally and medially. The hind tarsus is black except for the white base on the first segment, the tarsal claws are small and pectinate.

The cocoon is similar in shape to that of the other *Hyposoter* species but differs in its coloration and the disposition of the host's larval remains. Probably the most striking aspect is the way the host larval skin covers the entire dorsal aspect of the cocoon which is nearly white (figs. 45c, 46). The cocoon is 3.6 x 6.8 to 4.2 x 7.5 mm. somewhat larger than that of *Hyposoter* n. sp.

This species is a solitary internal primary parasite that attacks and emerges from the larva. The winter is passed in the cocoon stage and emergence occurs in the spring. *Hyposoter* species usually attack exposed larvae and have a rather wide range of hosts. It is possible that they utilize alternate hosts occurring in the same habitats as the tussock moth.

19. *Hyposoter* n. sp.

(Ichneumonidae: Porizontinae)

Figures 45a, 45b

This species is a very common parasite of the tussock moth. It is a smaller species than *H. fugitivus pacificus*, about 4.5 to 6.5 mm. The head, thorax, and abdomen are black, and the hind corner of the pronotum lacks the white marking evident in *H. f. pacificus*. The tegula, mandibles, and palps are white. Though the abdomen is generally black, the second and third abdominal tergites are sometimes infused with brown. The front leg is light colored, but the coxa is sometimes darker. The middle coxa is black, and the remainder of the leg is light colored. One of the features that readily distinguishes this species from *H. f. pacificus* is that the hind coxa, and commonly the first trochanter, are black. The femur is reddish brown, while the tibia exhibits a black and white pattern; black subbasally and apically, and light or white basally and medially. The hind tarsus is mostly black, but the basal segment of the middle tarsus is light colored. The ovipositor and tarsal claws are similar to *H. f. pacificus*.

Though slightly smaller and patterned differently, the cocoon is similar to *H. f. pacificus*. Its size is about 2.2 x 5.2 to 3.6 x 7.1 mm. The background color of the cocoon is tan to gray, and normally there is a distinct mottling of dark brown or black in a random pattern. In undisturbed specimens, the host larval skin is attached near one end on the dorsal surface of the cocoon. Usually, the skin appears to be attached at the larval prolegs (figs. 45a, 45b).

The parasite attacks and emerges from the larva; winter is passed in the cocoon stage. Emergence takes place about the time of tussock moth egg hatch and adults can be seen in flight through July (Mason 1976). Dahlsten et al. (1977) observed two peaks in *Hyposoter* species emergence from field-collected, laboratory-reared material. They speculated that the emergence pattern of *H. f. pacificus* was different from *Hyposoter* n. sp., suggesting biological differences between these two species utilizing the same host.

20. *Mesochorus* sp.

(Ichneumonidae: Mesochorinae)

Figure 10

This is a secondary parasite emerging from cocoons of *Phobocampe* n. sp. It is a rather small ichneumonid of from 4.0 to 6.5 mm, but usually at the smaller end of that range in size. The head, thorax, and legs are light yellowish brown to somewhat lighter; the hind tibia is darker apically. The first and second abdominal tergites are dark brown; the third tergite is lighter brown to yellowish; and the remaining distal tergites vary from brown to yellowish. The abdomen of the male terminates in two thin styli, and that of the female in a short ovipositor protected by a broad sheath. The antenna is longer than the forewing length. A conspicuous diamond-shaped areolet (AR) is present in the forewing (fig. 10), and the hindwing is characterized by its lack of a discoidella intersecting the nervellus.

21. *Apanteles* spp.

(Braconidae: Microgasterinae)

Figures 9, 49

These rather small, 2.4- to 3.4-mm, species occur sporadically as internal solitary primary parasites reared from late-instar larvae.

The microgasterines are characterized by lack of a radial vein (fig. 9), by an abdomen broadly joined to the thorax, and by a rather small, heavily sculptured abdomen. One of the more common of the two *Apanteles* species is black bodied with yellowish-brown legs, and palps. The antenna has 18 segments. The ovipositor is short and barely extends beyond the abdomen.

An ellipsoid cocoon (1.5- x 3.6- to 1.9- x 5.6-mm) composed of loosely spun fibers over a more dense capsule (fig. 49) is formed some distance from the host late larval remains. Although the cocoon is normally white, it sometimes has a tinge of green.

22. *Meteorus tersus* Muesebeck

(Braconidae: Euphorinae)

Figures 16, 44

Body size is approximately 3.6 to 5.0 mm; ovipositor 0.8 to 0.9 mm. The general body color is yellowish brown with dark-brown markings in the ocellar area, the occiput, mesonotum, propodeum, and first and posterior abdominal segments. Sculpturing, or lack of it, is striking, as on the first abdominal tergite which is striate posteriorly, and on the second and third abdominal tergites which are fused and shiny. The 33-segmented antenna is longer than the body.

This species is a solitary internal larval parasite. It emerges as a mature larva from the host larval skin and spins a cocoon that is roughly spindle shaped with blunt ends, 1.7 x 4.6 to 1.9 x 4.7 mm (fig. 44). The terminal strand of silk is characteristic; and under natural conditions, the cocoon will be found suspended from the foliage by this thread. In the spring the adult parasite emerges from the cocoon by cutting around the cocoon and pushing the cap back.

23. *Bracon xanthonotus* Ashmead

(Braconidae: Blacinae)

Figures 7, 50

This species is a rather common parasite in California,[5/] though it appears less commonly elsewhere in the range of tussock moth. It is a

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[5/] Based in part on examination of museum specimens housed at Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon; a letter to Dr. C. G. Thompson from Dr. R. Ryan, July 28, 1971, on file at same location; and Dahlsten et al. (1977).

gregarious primary parasite emerging from cocooned ultimate-instar host larvae. Cocoons of the parasites are formed in a clump, attached or close to the host larval remains. The mass of cocoons pictured in figure 50 measures 5 x 9 mm. Adults are 2.6 to 3.2 mm and are dark bodied with yellowish-brown markings. Markings on the head occur along the eye margins and at the base of the antenna, gena, and mandibles. Variable yellow markings occur on the mesonotum, second abdominal segment, and the legs. A deeply emarginate clypeus gives the impression of a pit above the mandibles. Antennae of females have 24 segments and antennae of males, 2 The ovipositor is shorter than the hind femur (0.6 to 0.7 mm). Forewing has a large prominent areolet (AR) (Fig. 7).

Hypopteromalus percussor acts as a secondary parasite attacking cocoons of *B. xanthonotus* (Dahlsten et al. 1977) (see section 27).

24. *Trichogramma minutum* Riley

(Chalcidoidea: Trichogrammatidae)

Figure 1

These are minute (0.3 to 0.6 mm), yellow-bodied insects with uniformly yellow legs. In males, the abdomen and thorax are partly brownish. The compound eyes and ocelli of both sexes are bright red. Males are further distinguished by prominent antennal setae, some of which exceed the length of individual antennal segments. The antenna of the female has an enlarged terminal segment. The arrangement of setae in the forewings is in distinct rows (fig. 1). In the hindwing the length of the marginal fringe exceeds the width of the wing. The tarsi have 3 segments.

The species is a very common solitary or gregarious parasite emerging from the tussock moth egg. Laboratory emergence from field collected eggs can occur without cold shock.

According to Dahlsten (personal communication), *Trichogramma californica* Nagarkatti and Nagaraja is as common as *T. minutum* in California. He states that *T. californica* displays more dark patterning than *T. minutum*; females of *T. minutum* are uniformly yellow, while females of *T. californica* have a dark abdomen.

25. *Tetrastichus* spp.

(Chalcidoidea: Eulophidae)

Figure 3

Two species of *Tetrastichus* have been reared from the tussock moth; one from the egg, another from small larvae.

The *Tetrastichus* species reared from the egg exhibits striking sexual dimorphism. Both sexes are small, 1.4 to 1.6 mm, and have red compound eyes. The general body color of the male is yellow, with the dorsum of thorax and abdomen infused with brown. The female is black, with brown or pale-colored legs and antennae. The elbowed antenna has 5 flagellar segments in the female and 6 in the male. Also, the scape on the male's

antenna is enlarged; larger in diameter than the femora. In the forewing the stigmal vein is less than half as long as the antennal scape. This egg parasite has appeared commonly in egg masses collected in New Mexico.[6/] Single and double emergences occur from individual eggs.

Another species of *Tetrastichus* was reared from late first- or second-instar larvae by Dahlsten et al. (1977), but specimens are unavailable for study.

26. *Telenomus californicus* Ashmead

(Serphoidea: Scelionidae)

Figure 2

This species is very common and has been the dominant egg parasite in some collection locations (Mason 1976, Dahlsten et al. 1977).

The adult wasps are small (1.0 to 1.2 mm), about intermediate in size between *Trichogramma minutum* and the egg-attacking *Tetrastichus*. The body and legs are black, except for some lighter coloration on distal portions of the legs. In the male the antennal flagellum has 11 segments and is filiform; in the female it has 10 segments and is more capitate. The scape is about as long as the width of the vertex. The vertex is rather wide, about 1-1/2 times as wide as the height of the compound eye. The abdomen is constricted where it joins the thorax, and the abdominal tergites are smooth with rounded lateral margins. Setae on the forewing are evenly distributed, and the stigmal vein (stv) (fig. 2) is as long or longer than the antennal scape. The marginal fringe on the hindwings is much shorter than the width of the wing. The tarsi have 5 segments.

27. *Hypopteromalus percussor* Girault

(Chalcidoidea: Pteromalidae)

Figure 5

According to Dahlsten et al. (1977), this species is a secondary parasite of *Bracon xanthonotus*. *H. percussor* emerges from cocoons of that gregarious species (see section 23).

These chalcidoids are 1.8 to 3.1 mm in length and are bright metallic green or blue. The abdomen of the male is dark brown to slightly metallic with a yellow band at the second tergite. The legs are mostly yellow, with the femora darker brown in the female.

[6/] Personal communication with Dr. D. Jennings, formerly of the Rocky Mountain Forest and Range Experiment Station, Albuquerque, New Mexico.

28. *Dibrachys cavus* (Walk.)

(Chalcidoidea: Pteromalidae)

Figure 6

This is an uncommon parasite which emerges from the tussock moth cocoon (Bedard 1938). Based on the broad host range of this species (Peck 1963), it can likely operate as either a primary or secondary parasite of the tussock moth.

It is a rather small (1.6- to 2.6-mm) wasp with a dark metallic head and thorax and a shiny, dark-brown to nearly black abdomen. The abdomen of the male is light brown with a yellow band. The legs of both sexes are yellowish brown with the coxae darker. Forewing has a very short postmarginal vein (pmv, fig. 6).

29. *Monodontomerus* spp.

(Chalcidoidea: Torymidae)

Figures 4, 25

Two species, *M. dentipes* (Dalman)[7/] [8/] (Bedard 1938) and *M. saltuosus* Grissell (Dahlsten et al. 1977), have been recorded as primary and secondary parasites, respectively, of tussock moth. The following description will distinguish *Monodontomerus* from the other genera mentioned herein.

These are small species, 2.9- to 3.6-mm, with ovipositors as long as 1.2 mm. The head, thorax, abdomen, coxae, and femora dark metallic green; the front and middle femora sometimes lacking the metallic luster. The tarsi and tibiae tend to brownish or yellowish brown. The most striking distinguishing characters are the enlarged hind coxa and the presence of the tooth near the distal end, on the ventral aspect of the hind femur (fig. 25). There is also an enlarged brown area near the stigma in the forewing (fig. 4). Females have a long prominent ovipositor extending beyond the end of the abdomen.

30. *Brachymeria ovata ovata* (Say)

(Chalcidoidea: Chalcididae)

Figure 24

This species (4.9- to 6.1-mm) is easily identified by its black and yellow patterning and by the shape of the hind leg. The general body color is black with yellow on the tegula, the distal end of the femora, both ends of the tibiae, and the tarsi. Punctations on the thorax are very

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[7/] Jennings, D. T. 1975. Natural enemies of the Douglas-fir tussock moth in the Central Rocky Mountains and the Southwest. Unpublished progress report on file at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

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coarse, contrasting with the second abdominal tergite which is smooth and shiny. The petiole is so foreshortened as to appear to be absent. The hind femur is greatly enlarged and has a row of prominent teeth on its lower surface where it fits against the curved tibia (fig. 24). This species emerges from tussock moth hosts collected as cocoons (Dahlsten et al. 1977; also see footnote 8).

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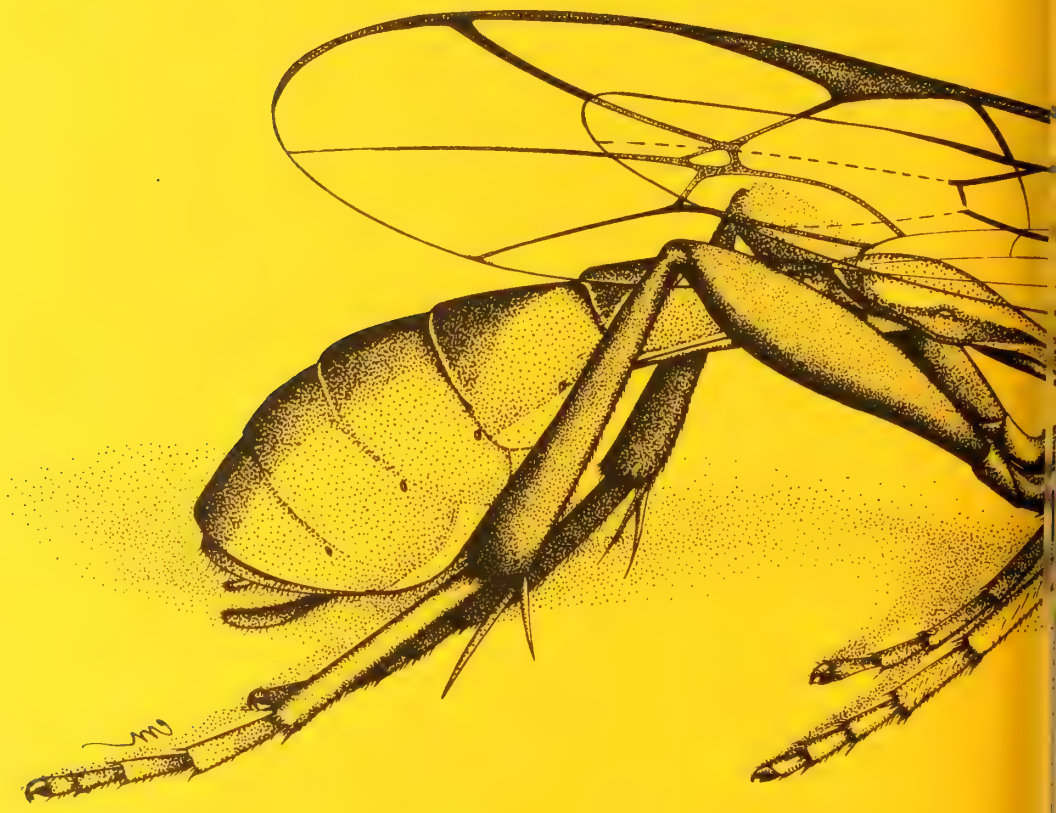

1977

USDA FOREST SERVICE RESEARCH PAPER PNW-217

Field Survival and Growth of Douglas-fir by Age and Size of Nursery Stock

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Field Survival and Growth of Douglas-fir by Age and Size of Nursery Stock

Reference Abstract

Edgren, James W.
1977. Field survival and growth of Douglas-fir by age and size of nursery stock. USDA For. Serv. Res. Pap. PNW-217, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Douglas-fir transplant stock survived better and grew more during the fourth season after planting than seedling stock from the same seed source when planted in clearcuts in the Oregon Cascade Range.

KEYWORDS: Growth (outplant) -)stock size, nursery transplants, seedling survival, Douglas-fir, *Pseudotsuga menziesii*.

RESEARCH SUMMARY

Research Paper PNW-217

1977

Seedlings and transplants from two Douglas-fir seed sources were planted near Oakridge, Oregon, in both fall and spring of 2 successive years to study field survival and growth in relation to nursery stock age and size. Height, diameter, and ovendry weight were the stock variables measured. Seedling size increased from 1+0 through 3+0. Both transplant classes averaged slightly shorter and heavier than 2+0 stock; 2+1's were slightly taller and heavier than 1+1's; 3+0 stock was tallest and heaviest. In general, transplants performed significantly better than seedlings. Other comparisons were also statistically significant but real differences were small. Actual survival and growth did not differ enough to warrant a recommendation of transplants over seedlings. Ranking of survival and growth during the fourth growing season for the 3,000-foot (914-m) and 3,500-foot (1 067-m) seed sources was:

Rank	Survival				Growth			
	3,000 feet		3,500 feet		3,000 feet		3,500 feet	
	Age class	Percent	Age class	Percent	Age class	cm	Age class	cm
1	1+1	76	2+1	56	1+1	27.1	1+1	23.2
2	2+1	68	1+1	54	2+1	26.4	2+1	22.6
3	3+0	65	3+0	49	3+0	25.3	1+0	20.0
4	2+0	64	2+0	47	1+0	25.2	3+0	19.9
5	1+0	55	1+0	32	2+0	23.4	2+0	19.3

The study was conducted on moderate to steep, relatively clean, south slopes judged by local foresters to be difficult sites. Results should apply on the west slopes of the Cascade Range in all areas with regeneration problems similar to those on the Oakridge Ranger District.

Introduction

This paper reports results of a study of field survival and growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings and transplants produced at Wind River Nursery near Carson, Washington, and transplants grown at the Westfir Transplant Nursery near Oakridge, Oregon. Stock was planted on the Oakridge Ranger District, Willamette National Forest, on sites chosen for their reforestation difficulty. Most units were on south- or southwest-facing slopes though three were nearly flat. Most had been burned 1 or 2 years before the planting and were clear of logging debris and vegetation. Two units were heavily vegetated; one contained much logging debris.

Study Design and Installation

Seed sources from the McKenzie and Lowell Ranger Districts of the Willamette National Forest from 914-meter (3,000-foot) and 1 067-meter (3,500-foot) elevation, respectively, were used at appropriate elevations. Seedlings of seven age-class lots were planted: 1+0, 2+0, and 3+0 from Wind River Nursery and 1+1 and 2+1 from Wind River and from the Westfir Transplant Nursery. The study required 12 clearcut units, 3 for each seed source in each of 2 successive years of installation. Trees were planted in blocks containing 14 rows of 25 trees each--1 row randomly assigned to each of the seven age-class lots planted in the fall and again in the spring. Blocks were replicated three times in each unit; spacing was 2.4 by 2.4 meters (8 by 8 feet), rows were oriented down the slopes. This arrangement was analyzed as a completely random split-plot design.

Trees were taken from nursery beds and graded by nursery personnel. All stock planted during a given season was lifted within 2 days and stored at Westfir in a refrigerated van until planted. All trees in a given block and season were planted by the same planter. As stock was packed for transport to the study area, two bags of 25 trees each from each age class lot were removed for tree measurements in the laboratory. Laboratory samples were collected during fall and spring of year 1 and fall of year 2. Collections were averaged together within age classes to characterize nursery stock. Nursery data were not analyzed statistically.

Data Collection

Nursery stock stem diameter 1 centimeter (0.39 in) below the cotyledonary node, stem height from the cotyledonary node to the tip of the terminal bud, and ovendry top and root weight after drying to constant weight at 80 °C (176 °F) were measured in the laboratory. Survival percent, height growth, and total height were recorded at the end of each of four growing seasons. Only 4th-year data are reported here.

Results and Discussion

NURSERY STOCK

For source 3,000 (McKenzie Ranger District), 3+0 seedlings were taller, larger in diameter, and heavier than 2+0 and 1+0 seedlings. Transplants were shorter than 2+0 seedlings, 2+1's shorter than 1+1's (table 1). Stock of source 3,500 (Lowell Ranger District) was similar but 1+1's were larger than 2+0's and 2+1's larger than 1+1's. Frost has always been a problem at Wind River Nursery and may have influenced seedling sizes, differentially between sources, since source 3,500 could be expected to be more frost resistant than source 3,000. Frost occurrence probably did not adversely affect field growth of individual trees.[1/]

1/ Edgren, James W. 1972. Growth of frost-damaged Douglas-fir seedlings. USDA For. Serv. Res. Note PNW-181, 8 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Table 1--*Average nursery stock characteristics of five age class lots for Douglas-fir seedlings from two seed sources*[1/]

Age class[2/]	Source, 3,000 feet				Source, 3,500 feet			
	Height[3/]	Diam-eter[4/]	Dry weight	Top-root ratio	Height[3/]	Diam-eter[4/]	Dry weight	Top-root ratio
	cm	mm	g		cm	mm	g	
1+0	7.4	1.5	0.5	1.5	6.4	1.4	0.4	1.6
2+0	21.3	3.6	3.4	2.2	19.1	3.4	4.1	1.8
3+0	27.7	6.1	10.4	2.1	27.6	5.2	8.2	1.9
1+1	16.8	4.4	4.5	1.6	19.7	4.6	5.2	1.7
2+1	15.9	5.0	6.2	1.3	20.9	5.3	8.4	1.4

[1/] Basis is 150 trees per age class per source.

[2/] 1+0, 2+0, and 3+0 were from Wind River Nursery; 1+1 and 2+1 were from Wind River Nursery and from Westfir Transplant Nursery.

[3/] For inches, multiply by 0.3937.

[4/] For inches, multiply by .03937.

Dry weight top-root ratios (T/R) of 2+0 and 3+0 were highest for each source; ratios of 2+1's were lowest. Two-year-old transplants (1+1) had intermediate ratios. First-year seedlings (1+0) had ratios most nearly like 1+1's (table 1).

FIELD SURVIVAL

Survival differences among age classes, though statistically significant were too small to influence management decisions (table 2). No differences were large enough to justify recommendation for or against a specific nursery or age class except for 1+0; use of 1+0 would not be wise. Other survival differences revealed here can readily be compensated for by planting a few extra trees per acre. However, it is of academic interest that transplants survived better than seedlings (see appendix).

Fall-planted stock survived best in the 1st planting year and spring-planted stock survived best the 2d year; the difference was significant (table 3). Again, no recommendation can be made as the difference was clearly attributable to weather conditions. After spring planting the 1st year, the weather turned warm and dry and remained so until mid-September. Trees planted during the first fall, 6 months earlier, probably were better established going into the dry summer. Weather during the second summer was unusually cool and wet and seedlings planted that spring benefited. Low survival of source 3,500 planted during year 1 can be attributed to vegetative competition.

FIELD GROWTH

Like survival differences, some growth differences were statistically significant but not large enough to influence management decisions (table 2). Transplants of source 3,000 grew significantly better than seedlings; those from Westfir outperformed those from Wind River. No significant growth differences occurred among age classes of source 3,500, probably because stock planted during the 2d year was extensively damaged by deer browsing in two of three units planted that year.

Table 2--*Average survival, height growth, and total height of Douglas-fir trees after 4 years in the field, by nursery age class and seed source*

Age class[1]	Source, 3,000 feet			Source, 3,500 feet		
	Survival	Growth[2]	Total height[2]	Survival	Growth[2]	Total height[2]
	Percent	cm		Percent	cm	
1+0	55	25.2	65.9	32	20.0	56.2
2+0	64	23.4	67.4	47	19.3	62.5
3+0	65	25.3	80.4	49	19.9	65.9
1+1	76	27.1	77.8	54	23.2	75.7
2+1	68	26.4	72.7	56	22.6	71.9

[1] 1+0, 2+0, and 3+0 were from Wind River Nursery; 1+1 and 2+1 were from Wind River Nursery and from Westfir Transplant Nursery.

[2] For inches, multiply by 0.3937.

Table 3--*Survival and growth of seedlings from two Douglas-fir seed sources planted in fall and spring of 2 successive years*

Year	Season	Source, 3,000 feet		Source, 3,500 feet	
		Survival	Growth	Survival	Growth
		Percent	cm	Percent	cm
1	Fall	66.4	24.8	35.9	22.5
1	Spring	57.5	24.1	17.5	19.8
2	Fall	68.3	27.6	68.0	21.4
2	Spring	78.3	26.8	78.4	22.1
Statistical significance		**	N.S.	**	N.S.

** = significant at 99-percent level.
N.S. = not significant.

TOTAL HEIGHT OF PLANTED STOCK

Tallest nursery stock did not grow best. For source 3,000, 3+0 stock averaged 10.9 cm (4.3 in) taller than 1+1 stock (table 1). After 4 years, trees from 3+0 stock were only 2.6 cm (1.0 in) taller than 1+1's, an 8.3-cm (3.3-in) gain for 1+1 stock (table 2). For source 3,500, the differences are more striking. Though 3+0 stock averaged 7.9 cm (3.1 in) taller than 1+1 stock at the nursery, trees from 1+1's averaged 9.8 cm (3.8 in) taller than those from 3+0's--a 17.7-cm (7.0-in) gain for 1+1's after 4 years of growth. Similar comparisons can be made of 1+1's with 2+1's and also with 2+0's.

TOP-ROOT RATIO

As a measure of seedling quality, T/R (top-root ratio) by itself appears

to have limited application. Exclusive of 1+0's, stock with intermediate T/R's--1+1 transplants--performed best for both sources. Stock with either higher (2+0 and 3+0) or lower (2+1) ratios did not do as well. First-year seedlings (1+0), with T/R nearly the same as 1+1 in each source, performed poorest of all age classes in survival and about the same as 3+0 in growth. Clearly, it is impossible to generalize from these data about the influence of T/R on field growth and survival.

Conclusions

WHICH AGE CLASS TO USE?

These data strongly suggest that:

1. Two-year-old Douglas-fir seedlings are adequate for most moderate to steep, clean, south slopes (a) on the west slopes of the Oregon Cascade Range north of Crater Lake, (b) on other areas easier to reforest within this locality, and (c) in other localities of Oregon and Washington where reforestation problems are similar to those experienced on difficult planting sites of the Oakridge Ranger District.

2. Two-year-old Douglas-fir transplants, although superior to other stock in a statistical sense, did not perform well enough to warrant a recommendation.

3. Use of 3+0 or 2+1 stock is not justified because of their greater expense, unimpressive performance relative to 2+0, and the 1-year additional lead time required to produce it.

4. Tallest nursery stock did not perform best.

5. Top-root ratio was not a good estimator of seedling quality.

Acknowledgment

I wish to thank personnel of the Oakridge Ranger District and Supervisor's Office, Willamette National Forest, and the Wind River Nursery, Gifford Pinchot National Forest. Their help made this study possible.

Appendix

IMPLICATIONS FOR FUTURE RESEARCH

Though transplants did not perform well enough in this study to warrant a recommendation for their use, their statistically significant edge over seedlings cannot be ignored. These data suggest that the act of transplanting was primarily responsible for this edge. I suggest we must learn to produce a seedling with physical and physiological characteristics of a transplant. Three things occur in transplanting that seedling nursery stock does not experience. We must accomplish these by improved cultural practices in original seed beds, avoiding the added expense of transplanting.

First, the plants are disturbed during lifting and planting. This disturbance has long been recognized as beneficial.[2/] For many years, standard nursery practice has been to undercut seedlings early in spring to simulate the disturbance caused by transplanting. However, the single undercutting has questionable value.[3/] A promising technique called wrenching[4/] has been developed in New Zealand for Monterey pine (*Pinus radiata* D. Don) and has also been used there on Douglas-fir. The technique uses repeated passes of a cutting blade under seedlings in the nursery bed at intervals of 2 to 4 weeks to stop top growth and stimulate a fibrous root system. We must examine wrenching in efforts to produce transplantlike seedlings.

Second, uniform bed density must be considered in any effort to produce improved, transplantlike seedlings. At the time seedlings used in this study were grown, the density target was 40 seedlings or more per square foot. Transplants are grown at 8 to 10 or fewer per square foot. Current nursery studies[5/] suggest that a good bed density from a field standpoint may be no more than 20 seedlings per square foot. Possibly a good compromise between field performance and nursery economics will be between 20 and 30 2+0 Douglas-fir seedlings per square foot, near the density range recommended for efficient wrenching. Lower densities and uniform distribution hold promise for improved field performance. Less space is required for low density seedlings than for transplants; and uniform spacing reduces unequal competition and seedling size variability, thereby reducing culls and permitting efficient use of valuable seed.

Third, transplants may have been better performers than seedlings because they were subjected to more intensive grading and consequently more selective culling than seedlings--before transplanting, during growth after transplanting, and again before outplanting. Many seedlings that would have died when outplanted were thus weeded out by the transplanting process. Therefore, the transplanted stock was of higher quality. This culling function, achieved as a fringe benefit of transplanting, may not be as important for seedlings grown at realistic uniform bed densities.

[2/] Foster, C. H. 1932. Improvements in planting stock production. J. For. 30:797-799.

[3/] Edgren, James W. Field performance of undercut coastal and Rocky Mountain Douglas-fir 2+0 seedlings. (In preparation for publication, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.)

[4/] Rook, D. A. 1971. Effect of undercutting and wrenching on growth of *Pinus radiata* D. Don seedlings. J. Appl. Ecol. 8:477-490.

[5/] Edgren, James W. 1975. Douglas-fir 2+0 nursery stock size and first-year field performance in relation to seedbed density. Paper presented to Service-wide Planting Stock Conference, Coeur d'Alene, Idaho.

Demand for planting stock is increasing each year because more acres are planted with more trees per acre. Though lower seed bed densities may increase the number of nursery acres needed, nursery acres are more easily increased than seed supplies because good seed years do not occur frequently and regularly. Seed supplies could become the limiting factor in reforestation of some sites if we do not use seed efficiently. Overdense seed beds constitute inefficient use of seed. Fewer culls, resulting from lowered seed bed densities, also permit the production of more acceptable seedlings from a given number of acres.

In summary, future research on Douglas-fir nursery stock should concentrate on seed bed density and wrenching, with the goal of producing a 2-year-old seedling that performs like a transplant in the field. The 2-year period is desirable for at least three reasons: (1) a 3d year in this study did not help either seedlings or transplants, and either category grown at the proper density for normal 3-year growth would likely become too large for efficient handling and planting; (2) a 3-year nursery period requires foresters to order stock too far in advance for efficient planning; and (3) 2-year-old seedlings experience less setback from lifting and planting than older seedlings.

Future research on seedling performance must include nursery cultural practices and physical measurements and must test across a range of site conditions likely to be encountered naturally or created artificially in the area for which the seedling is intended. We must not lose sight of the fact that reforestation constitutes a closed system. Manipulation of any of its components influences what happens in the other components.

* * * * * *

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1977. Field survival and growth of Douglas-fir by age and size of nursery stock. USDA For. Serv. Res. Pap. PNW-217, 6 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

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KEYWORDS: Growth (outplant) -)stock size, nursery transplants, seedling survival, Douglas-fir *Pseudotsuga menziesii*.

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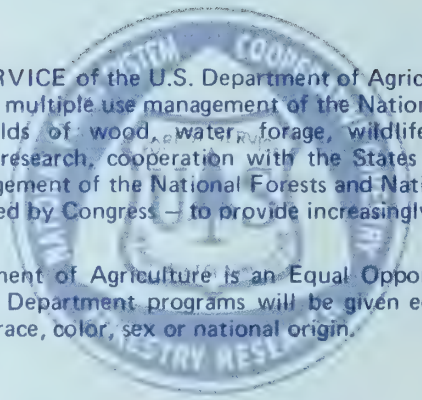

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SAMPLING LOW DENSITY POPULATIONS OF THE DOUGLAS-FIR TUSSOCK MOTH

BY FREQUENCY OF OCCURRENCE IN THE LOWER TREE CROWN

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Richard R. Mason

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

Tree diagrams on cover illustrate the expected vertical distribution over the tree of small tussock moth larvae (shaded symbols). The distributions were generated from random numbers according to a 4:2:1 probability of occurrence from top to bottom.

Sampling Low Density Populations of the Douglas-fir Tussock Moth by Frequency of Occurrence in the Lower Tree Crown

Reference Abstract

Mason, Richard R.
1977. Sampling low density populations of the Douglas-fir tussock moth by frequency of occurrence in the lower tree crown. USDA For. Serv. Res. Pap. PNW-216, 8 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A new method is described for rapidly estimating the larval density of low-level populations. Densities of 1.0 or fewer larvae per 1,000 sq in (0.64 sq m) of branch area in the midcrown of host trees can be predicted from the proportion of sample units that are infested in the lower tree crown. This procedure is an improvement over the conventional midcrown sampling method because observations can be made in the more accessible lower crown without clipping and measuring branches. The technique is especially applicable to low-level populations which require the examination of large amounts of foliage to estimate larval density.

KEYWORDS: Population sampling (insect), insects, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

'ESEARCH SUMMARY

*esearch Paper PNW-*216

977

Density of larvae on host tree oliage has become the accepted index or evaluating tussock moth popula- ions. Density is usually estimated n outbreaks by sampling midcrown oliage with a pole pruner and basket. owever, such a method is impractical r sampling low-density populations ere larvae are sparsely distributed the foliage and rarely encountered sample branches. It is important be able to measure low-density pulations because potential outbreaks n be detected at least 2 years in vance of tree damage by observing nual trends in numbers of small rvae.

A new method has been developed l described for sampling early tars in low-density populations. arge amount of foliage can be exam- d quickly and easily because all a are collected from accessible er crown branches and branch area s not have to be measured. Selected ole branches within reach are beaten place over a portable drop cloth on ch dislodged larvae can be observed.

For average sample unit sizes the number of larvae in low-density populations of less than 1.0 per 1000 in^2 (0.64 m^2) follows a Poisson distribution. Using the theoretical relationship from this distribution mean density of larvae in the lower crown can be approximated from the proportion of samples infested. Larval density in the midcrown is calculated by correcting the lower crown density according to the expected vertical distribution of larvae in the tree. The model derived from this procedure is $\hat{M} = -4 \ln(1 - p_x)$, where $\hat{M}$ is the midcrown density of early instars and p_x is the proportion of infested 3-branch samples in the lower crown.

This sampling method has been field tested in low-density populations for two seasons and found to produce results comparable to the conventional method of sampling foliage in the midcrown with a pole pruner.

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Introduction

Conventional methods for sampling larvae of the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) involve examining and measuring branches removed from the middle one-third of host trees with a pole pruner and basket (Mason 1970). Density of the population is expressed in terms of larvae per 1,000 in^2 (0.64 m^2) of branch area. This method is adequate for estimating population densities in sub-outbreak and outbreak conditions where larval density exceeds 1.0 larva per 1,000 in^2 (0.64 m^2) of branch area. Conventional sampling is unsatisfactory for very low populations with a density that may be far below the 1.0 level. Tussock moth densities are apparently low most of the time and, as a result, are not easily quantified by normal sampling procedures.

In population studies, sample plots usually consist of 12 to 15 trees from which 5,000 to 8,000 in^2 (3.2-5.1 m^2) of branch area or about 500 in^2 (0.32 m^2) per tree are removed for examination. At this rate a very large number of trees must be sampled to quantify low density populations. As illustrated below, when population density is less than 0.1, the average number of trees required to sample a single larva is completely impractical by present standards.

Number larvae per 1,000 in^2 (0.64 m^2)	Average branch area per larva	Average number sample trees per larva sampled
1	1,000 in^2 (0.64 m^2)	2
.1	10,000 in^2 (6.4 m^2)	20
.01	100,000 in^2 (64.0 m^2)	200
.001	1,000,000 in^2 (640 m^2)	2,000

A modified procedure is needed for sampling low density populations. To be of practical use, such a procedure must meet at least two criteria: (1) larval density must be expressed in standard units of branch area and, (2) a sample crew must be able to examine large amounts of foliage on each plot within a reasonable amount of time. Such a sampling method is described in this paper. Most data discussed are for small larvae (1st-2nd instars). The method may also have application for sampling older larvae.

The Sampling Approach

The first criterion of standardization can be satisfied by a basic relationship that exists between the mean density of larvae and the proportion of sample units that contain one or more larvae. When larvae are abundant in an area, they will appear in a greater proportion of the samples than when they are rare. The exact form of this relationship depends on the size of the sample unit and the frequency distribution of data. The relationship can be determined by regression analysis or by fitting a theoretical mathematical distribution to field data.

Once the relationship is known, mean density can be estimated from the proportion of infested samples. The advantage of the method is that branch area need not be measured nor larvae counted. Sample units are recorded as infested or not infested. The general technique has been developed and recommended for sampling other insects (Gerrard and Chiang 1970, Wilson and Gerrard 1971) and for measuring vegetation (Dice 1952).

The second criterion for rapid foliage examination can be satisfied by sampling low tree branches within reach of the average person. This eliminates the need for aerial sampling equipment and permits a great deal more foliage to be examined in the same amount of time than by the conventional midcrown method. The success of sampling the lower crown assumes that density of tussock moth larvae in that lower stratum is a satisfactory index which can be calibrated with population density over the entire tree.

Frequency of Infested Sample Units

Sample data collected on plots from several locations in the West over the last 9 years were used to determine the needed relationship between mean density and proportion of infested samples. Fortunately, data were available from 50 plots where density of small larvae was less than 1.0 per 1,000 in^2 and could be used to calculate this relationship for low density populations of tussock moth.

The plots ranged in size from 10 to 40 trees. The primary sample unit was three 18- to 22-in (46-56 cm) branches from the midcrown, i.e. the crown originating from the middle one-third of the bole, of each tree. Density of the larval population was calculated in the conventional manner by

$$M = 1000 \frac{1}{n} \sum_{i=1}^{n} \left(\frac{y_i}{a_i}\right); \qquad (1)$$

where

M = mean number of larvae/1,000 in^2 of branch area in the midcrown.

y_i = number of larvae on a three-branch sample unit from the midcrown of tree i.

a_i = in^2 of branch area sampled in tree i.

n = number of trees sampled.

The proportion, p_y, of midcrown sample units infested was calculated by

$$p_y = r/n \qquad (2)$$

where r is the number of sample units possessing one or more larvae.

The relationship of M to p_y is plotted in figure 1. A linear regression fitted to the data, shown by the broken line, accounts for 89 percent of the variation. Midcrown larval density over the range of these data can be estimated by the regression equation

$$\hat{M} = .007 + 2.109\ p_y. \qquad (3)$$

The slope of 2.109 means that when infested sample units contain only one larva, which is usually the case on low density plots, the three-branch sample unit averaged 474 in^2 (0.30 m^2). The regression line does not pass through the origin, and it would probably tend to overestimate very low densities. The line can be forced through the origin with little change in the slope coefficient so that larval density may be better estimated by

$$\hat{M} = 2.152\ p_y. \qquad (4)$$

The occurrence of larvae on samples at low densities is a relatively rare event and can also be shown to follow a Poisson distribution where variance equals the mean. Although agreement with this distribution is the accepted test for randomness, it does not necessarily mean that larvae at low densities are actually randomly distributed in the foliage. Size of the sample unit has an important effect on tests for distribution, and the branch samples in this case are probably too small to detect any aggregation in the population. Nevertheless, larval density on a plot can also be calculated from the theoretical distribution of the Poisson variables (Fisher 1941) by

$$\bar{y} = -\ln(1-p_y); \qquad (5)$$

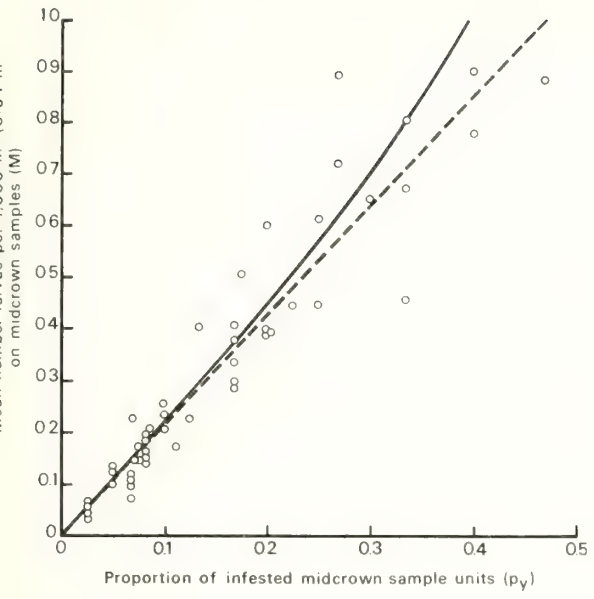

Figure 1.--Relationship between density of small tussock moth larvae (M) and proportion of infested sample units (p_y) in the midcrown.

where

$\bar{y}$ = mean density of larvae/sample unit in the midcrown.

ln(a) = natural logarithm of a.

Since the average sample unit size is about 500 in^2 (0.32 m^2), larval density per 1,000 in^2 (0.64 m^2) can be approximated by

$$\hat{M} = -2 \ln(1-p_y). \qquad (6)$$

This relationship is shown by the solid line in figure 1. Because of its theoretical base, equation (6) is probably a better model than equation (4) for estimating density below the range of the data shown in figure 1. Neither equation is a completely satisfactory model for density levels above 1.0 when the measured distribution of larvae is non-random.

Lower Crown Density as a Population Index

The only published study of larval distributions in the tree crown was conducted in a small tussock moth outbreak in the Corral Creek area of the Modoc National Forest in 1966 (Mason 1970). In this investigation, larvae were found in different concentrations in all portions of the crown. The average distribution of all ages of larvae from top to bottom, for the same amount of foliage sampled, approximated a 4:2:1 ratio; i.e. twice and four times the density of larvae occurred on middle and upper crown samples as on lower crown samples. Middle crown samples were judged to be most representative of the whole tree and have since been used successfully as the standard for determining larval density.

Lower crown branches also clearly contain a fraction of the larval population and, although not as representative of the tree as midcrown branches, can be used to obtain a population index. Based on results of the earlier studies for all ages of larvae, we would expect populations of early instars in the lower crown to average about one-half the density of those in the standard middle crown. Late instars may have almost the same density in both crown levels due to a shift in distribution prior to pupation. For only first- and second-instar larvae, the actual ratio of means (R) of midcrown density (M) to lower-crown density (L) at Corral Creek averaged 2.41 over eight plots. The median R was 2.04 which, in this case, is probably a better measurement of central tendency.

M	L	R
---Larvae per 1,000 in^2 (0.64 m^2)---		
61.2	38.5	1.59
62.2	11.7	5.32
65.6	59.0	1.11
21.6	11.5	1.88
30.2	13.0	2.32
54.6	15.8	3.46
14.1	10.3	1.37
58.0	26.2	2.21

Mean R $\pm$ SE = 2.41 $\pm$ .49

Median R = 2.04

These data are from an outbreak with relatively high density populations. The ratios could differ in low density situations. Considering the dispersal habits of early instar larvae, there seems to be no compelling reason why similar R values would not be expected.

Estimating Population Density from Lower Crown Samples

If we use the same rationale for developing equation (6), density of larvae per 1,000 sq in^2 (0.64 m^2) in the crown from the lower one-third bole (L) can be estimated by

$$\hat{L} = -2 \ln(1-p_x); \qquad (7)$$

where

p_x = estimated proportion of sample units in the lower crown with one or more larvae.

Equation (7) assumes that the same frequency distribution of larvae and sample unit size apply in the lower crown as in the middle crown where data for developing the relationships were originally collected. Although larval density is less, there is no reason to expect a different distribution pattern of larvae in the lower crown. The size of branch samples examined in the lower crown, however, must be controlled to approximate the size of normal midcrown samples.

By accepting lower crown density as an index, midcrown density can now be estimated by

$$\hat{M} = R\hat{L}, \qquad (8)$$

or from the proportion of infested lower crown sample units by

$$\hat{M} = -2 R \ln(1-p_x). \qquad (9)$$

Without additional subsampling at each location, which is impractical, an average value of R must be assumed. A precise estimate may be unnecessary due to the relatively small effect of R over the range of low densities that we expect to measure. From what is presently known about the vertical distribution of larvae, a reasonable value of R for early instars seems to be about 2.0. Due to downward migration of older larvae, however, we suspect that R decreases through the season and may approach 1.0 by the time of pupation.

After substituting 2.0 for R in equation (9) the density of early instars can be estimated by

$$\hat{M} = -4 \ln(1-p_x). \qquad (10)$$

Equation (10) is graphed on a logarithmic scale in figure 2 to give expected densities for different values of p_x.

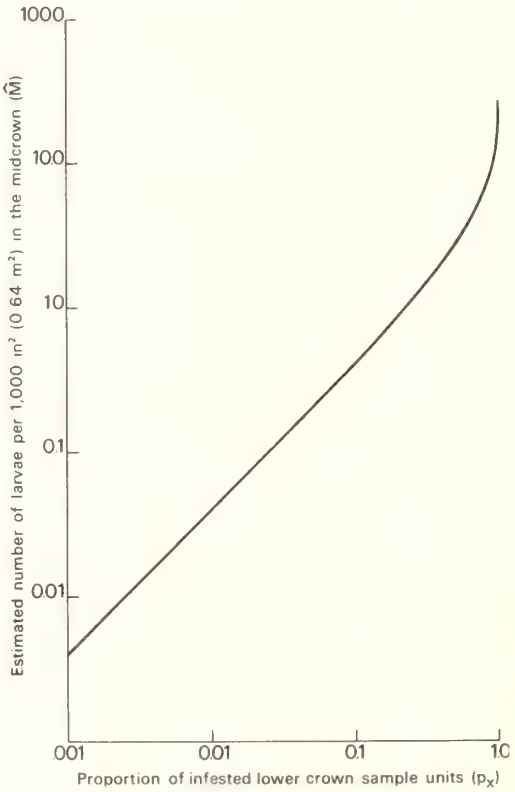

Figure 2.--Predicted relationship between proportion of lower crown sample units infested (p_x) and density of small tussock moth larvae in the midcrown ($\hat{M}$).

The equation shows that at midcrown densities of 1.0 or less larvae per 1,000 in^2 (0.64 m^2), fewer than 22 percent of the lower crown sample units will be infested. At midcrown densities of about 20 larvae per 1,000 in^2 (0.64 m^2) almost all lower crown sample units will have larvae. The model is most applicable to densities below the 0.1 level which cannot be estimated by any other practical method; but it should also be satisfactory for estimating higher densities up to at least 5.0 larvae per 1,000 in^2 (0.64 m^2). Theoretically, the model should tend to slightly underestimate densities over 1.0 because the Poisson distribution assumes randomness and does not consider that the aggregation of larvae on this sample unit size increases at higher densities (Dice 1948). Proportions and calculated densities for three values of R are listed in table 1 for easy conversion.

Field Application and Validation

An appealing advantage of sampling lower crown foliage is that branches can be examined in place without removing them from the tree. This is done by beating the foliage of three sample branches per tree over a hand-held drop cloth (fig. 3). Because of the assumption of similarity in sample unit size, care must be taken that the branches beaten are similar in size to those normally sampled in the midcrown. The beating cloth should not be placed under more than about 22 in (56 cm) of a branch. The only information noted for the three-branch sample unit is whether or not it contains at least one tussock moth larva. A larval count is not necessary because frequency of occurrence is determined only by presence, or absence, on the sample unit. If a larva is found on the first branch there is no reason to examine the other two.

Figure 3.--Sampling tussock moth larvae on lower crown foliage by beating branches over a hand-held drop cloth. Dimensions of the cloth are 24 x 48 in (61 x 123 cm). The cloth is supported in the corners by aluminum cross members. The photos illustrate the technique of sampling a range of heights in the lower crown with the portable drop cloth.

Table 1--*Table for converting proportion of infested lower crown samples* (p_x) *to density of larvae at midcrown* ($\hat{M}$). *Densities are calculated from* $\hat{M} = -2R \ln(1-p_x)$ *for three values of* R.[1/]

P_x	$\hat{M}$			P_x	$\hat{M}$		
	R = 1.0	R = 1.5	R = 2.0		R = 1.0	R = 1.5	R = 2.0
	No. per 1000 in^2 (0.64 m^2)				No. per 1000 in^2 (0.64 m^2)		
.001	.002	.003	.004	.31	.74	1.11	1.48
.002	.004	.006	.008	.32	.77	1.16	1.54
.003	.006	.009	.012	.33	.80	1.20	1.60
.004	.008	.012	.016	.34	.83	1.25	1.66
.005	.010	.015	.020	.35	.86	1.29	1.72
.006	.012	.018	.024	.36	.89	1.34	1.78
.007	.014	.021	.028	.37	.92	1.39	1.85
.008	.016	.024	.032	.38	.96	1.43	1.91
.009	.018	.027	.036	.39	.99	1.48	1.98
.01	.02	.03	.04	.40	1.02	1.53	2.04
.02	.04	.06	.08	.41	1.06	1.58	2.11
.03	.06	.09	.12	.42	1.09	1.63	2.18
.04	.08	.12	.16	.43	1.12	1.68	2.25
.05	.10	.15	.20	.44	1.16	1.74	2.32
.06	.12	.19	.25	.45	1.20	1.79	2.39
.07	.15	.22	.29	.46	1.23	1.85	2.46
.08	.17	.25	.33	.47	1.27	1.90	2.54
.09	.19	.28	.38	.48	1.31	1.96	2.62
.10	.21	.32	.42	.49	1.35	2.02	2.69
.11	.23	.35	.47	.50	1.39	2.08	2.77
.12	.26	.38	.51	.51	1.43	2.14	2.85
.13	.28	.42	.56	.52	1.47	2.20	2.94
.14	.30	.45	.60	.53	1.51	2.27	3.02
.15	.32	.49	.65	.54	1.55	2.33	3.11
.16	.35	.52	.70	.55	1.60	2.40	3.19
.17	.37	.56	.74	.56	1.64	2.46	3.28
.18	.40	.60	.79	.57	1.69	2.53	3.38
.19	.42	.63	.84	.58	1.74	2.60	3.47
.20	.45	.67	.89	.59	1.78	2.67	3.57
.21	.47	.71	.94	.60	1.83	2.75	3.67
.22	.50	.75	.99	.61	1.88	2.82	3.77
.23	.52	.78	1.04	.62	1.94	2.90	3.87
.24	.55	.82	1.10	.63	1.99	2.98	3.98
.25	.58	.86	1.15	.64	2.04	3.06	4.09
.26	.60	.90	1.20	.65	2.10	3.15	4.20
.27	.63	.94	1.26	.66	2.16	3.24	4.32
.28	.66	.99	1.31	.67	2.22	3.33	4.43
.29	.68	1.02	1.37	.68	2.28	3.42	4.56
.30	.71	1.07	1.43	.69	2.34	3.51	4.68
				.70	2.41	3.61	4.82

[1/] R = 2.0 is recommended for sampling 1st to 2d instars (small larvae), R = 1.5 for 3d to 4th instars (medium larvae), and R = 1.0 for 5th to 6th instars (large larvae).

A population density in the range of 0.1 to 1.0 larvae per 1,000 in^2 (0.64 m^2) will require a sample size of at least 100 trees for an estimate of p_x. Larger sample sizes will be needed for larval densities that are less than 0.1. The practical limits to sampling by this procedure are probably around 0.01 although estimates of lower density levels are possible.

Standard procedures for selecting sample trees and canvassing a plot area have not yet been fully developed. Sampling is restricted to trees with branches in the lower stratum that can be reached by hand. All trees in this category should be included in the sample as one proceeds through the area. To prevent bias, only lower branches should be sampled even though the tops of small understory trees can be reached. A sampling crew can satisfactorily cover a 2- to 5-acre (.4-2.0 ha) area by starting at a central point and radiating out in different directions. To cover a larger area, which may be necessary in very low density situations, a crew may have to proceed in the same direction along a swath through the area.

This modified method of sampling was tested on relatively low density populations at several field locations in 1975 and 1976. Results were compared with conventional midcrown sampling of early instars at the same general locations, but on different trees. Larval density was estimated from 15 sample trees using the conventional method, equation 1, and from 75 to 100 different trees with the lower crown method, equation 10.

Data from both sampling methods are compared graphically in a scatter diagram shown in figure 4. The comparison shows that density estimates from the two methods are similar, evidenced by the scatter of data points along the 45-degree slope of equality. A simple correlation analysis performed on the two sets of data showed that the model using p_x to estimate M accounted for 69 percent of the observed variation ($r = 0.831$; $n = 34$). This suggests that within the range of these data comparable results could be obtained by using either sampling method. Additional estimates of R were calculated for 1st-2d instars from the ratio $M/\hat{L}$ on each plot. These averaged $1.81 \pm .21$ (SE) over 34 plots and, thus, generally supported the value of R used in equation (10).[1/] Such encouraging results indicate that lower crown frequency sampling has good potential for estimating larval densities below the range from which previous data have been collected.

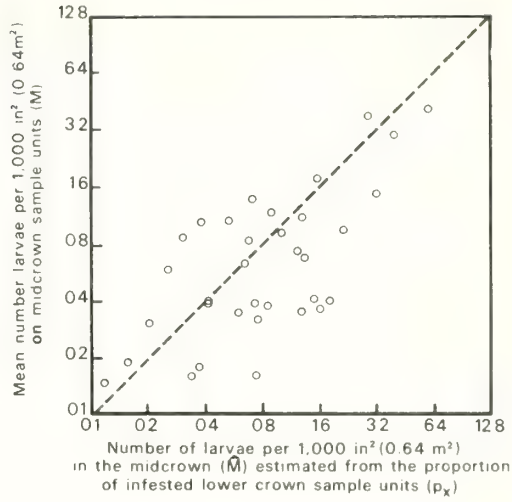
Mean number larvae per 1,000 in² (0.64m²) on midcrown sample units (M)
128
64
32
16
08
04
02
01
01 02 04 08 16 32 64 128
Number of larvae per 1,000 in² (0.64 m²) in the midcrown (M̂) estimated from the proportion of infested lower crown sample units (pₓ)

Figure 4.--Comparison of midcrown densities of small larvae estimated from midcrown samples and from proportion of infested lower crown samples.

[1/] The average value of R for 3'rd-4'th instars on 7 plots was lower, $.98 \pm .16$ (SE), which suggests that in low density populations there is a change in vertical distribution as larvae mature.

Acknowledgments

I am indebted to numerous individuals at the Forestry Sciences Laboratory, Corvallis, for their assistance in field testing this sampling procedure, but especially to T. R. Torgersen and B. E. Wickman for their suggestions and H. G. Paul for the design and construction of the portable drop cloths. I also thank W. S. Overton of Oregon State University for his statistical review.

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☆GPO 797-026

Mason, Richard R.
1977. Sampling low density populations of the Douglas-fir tussock moth by frequency of occurrence in the lower tree crown. USDA For. Serv. Res. Pap. PNW-216, 8 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A new method is described for rapidly estimating the larval density of low-level populations. Densities of 1.0 or fewer larvae per 1,000 sq in (0.64 sq m) of branch area in the midcrown of host trees can be predicted from the proportion of sample units that are infested in the lower tree crown. This procedure is an improvement over the conventional midcrown sampling method because observations can be made in the more accessible lower crown without clipping and measuring branches. The technique is especially applicable to low-level populations which require the examination of large amounts of foliage to estimate larval density.

KEYWORDS: Population sampling (insect), insects, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

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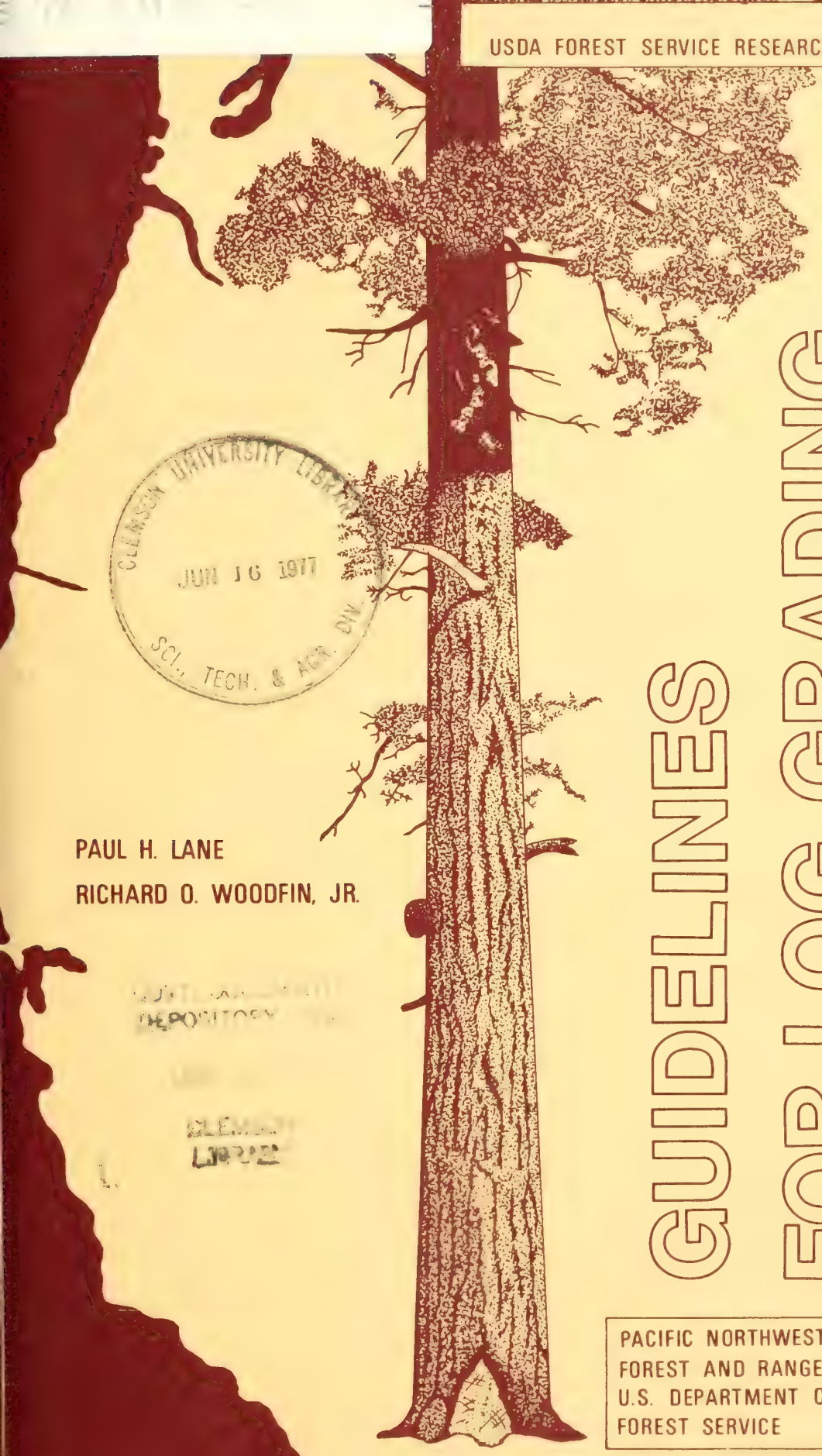
1977
USDA FOREST SERVICE RESEARCH PAPER PNW-218



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GUIDELINES FOR LOG GRADING COAST DOUGLAS-FIR

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METRIC CONVERSIONS

1 inch = 2.54 centimeters

1 foot = 0.3048 meter

1 meter = 39.370 inches

1 meter = 3.2808 feet

Diameter at breast height (d.b.h.)
= 4.5 feet = 54 inches = 1.37 meters

Nominal 16-foot log = 4.88 meters

PAUL H. LANE is Consultant, Forest Products Technologist, and RICHARD O. WOODFIN, JR., is Supervisory Research Forest Products Technologist, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Guidelines for Log Grading Coast Douglas-fir

Reference Abstract

Lane, Paul H., and Richard O. Woodfin, Jr.
1977. Guidelines for log grading Coast Douglas-fir. USDA For. Serv. Res. Pap. PNW-218, 14 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

This report is a photographic guide to the application of the new four-grade system for cruising Coast Douglas-fir. It is intended as both a training aid and illustration of features that lower grades.

KEYWORDS: Grading (log), timber cruising, defect indicators (wood quality), Coast Douglas-fir, *Pseudotsuga menziesii*, old-growth stands.

RESEARCH SUMMARY

Research Paper PNW-218

1977

This report presents guidelines for applying the four-grade system of timber cruising grades for Coast Douglas-fir. It is intended for use by timber cruisers and grading instructors to insure uniform application of the new grades. Photographs are used to define and describe log characteristics that are grading defects.

A summary of log grade specifications is included.

This publication, a supplement to "New Timber Cruising Grades for Coast Douglas-fir,"[1/] provides auxiliary information about log defects and the grading specifications described in the earlier paper. It is intended primarily to assist timber cruisers in grading coast-type, old-growth Douglas-fir.

General Rules for Applying the Grades

1. The grades are applied to live, standing, old-growth, coast-type Douglas-fir. "Old growth" is defined as timber estimated to be more than 100 years old. "Coast-type" is the botanical variety of Douglas-fir *Pseudotsuga menziesii* (Mirb.) Franco variety *menziesii*, growing west of the crest of the Cascade Range in Washington and Oregon and the Sierra Nevada Mountains of northern California.

   The grades are applicable to recently dead or blown down timber if, in the judgment of the cruiser, such timber has not deteriorated significantly--i.e., the expected yield of lumber or veneer would not be different from the same timber in a live and standing condition.

2. When the grades are applied, the tree stem is considered to be divided into nominal 16-foot (4.88 meters) consecutive segments or logs. The term "log" as used in this paper refers to the designated and uncut 16-foot section of a standing tree. If the cruising procedure specifies the inclusion of a trim allowance in the nominal 16-foot log length, the grading specifications must be applied to the entire length.

3. Each log is designated either "merchantable" or "nonmerchantable." Logs at least one-third sound are considered merchantable. Logs having a cruise volume deduction of more than two-thirds of their gross volume are designated "nonmerchantable" or "cull."

4. Each merchantable log is graded separately and without regard for the condition or grade of adjoining logs, *except when adjacent to a cull*. Logs meeting the specifications for Grades I, II, or III must be lowered one grade when they are adjacent to a cull log.

5. The grading specifications are applied to each log by "log faces." A log face is one-fourth the log circumference for the full length of the log.

   Log faces are established by the cruiser according to the presence (or absence) of log characteristics affecting the log grade. The objective is to select the best face (most knot-free) or the poorest (face with the largest percent of surface area covered by knots).

   Once the grading faces of a log are established, they cannot be shifted *except* for large burls (this exception is explained under item "7" in the following section on grading specifications).

6. The grading specifications are applied to each merchantable log, usually starting with the butt log and progressing up the tree stem.

   A tentative grade of each log is determined by applying the knot (or knot indicator) specifications--then the other grading criteria for such defects as scars, conks, or

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[1/] Lane, Paul H., Richard O. Woodfin, Jr., John W. Henley, and Marlin E. Plank. 1973. New timber cruising grades for Coast Douglas-fir. USDA For. Serv. Res. Pap. PNW-151, 12 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

bumps are applied to establish the final grade. For example, if the log segment is knot free, it is a potential Grade I; the grader would then look for other possible limiting defects to establish the final grade.

The grading specifications to be applied by the above general rules and summarized in table 1 are described in more detail in the following section.

Description of the Log Grading Specifications

1. *Sound knots* are live or dead limbs or limb stubs on a log that show no evidence of decay. They are important defects in grading as their presence means knots in the underlying wood (usually continuing to the pith of the log). Consequently, they lower value of logs for producing lumber, veneer, or other products. The number, size, and location of knots are important criteria in determining log grade (table 1).

   Knot size (diameter) is measured at the log surface, *inside* any limb bark that may be present, *but excluding* the limb collar or any swelling present at the surface juncture (fig. 1).

   Limbs causing knots may be live or dead and may protrude from the log surface (fig. 2) or be broken off, leaving a stub flush with the surface or an open depression (fig. 3). The only exception to these definitions of sound knots is for small epicormic branches described later in item 10.

2. *Rotten knots* are live or dead limbs or limb stubs that show evidence of decay or rot. They often appear as black bumps and may exude discolored pitch (fig. 4). Rotten knots indicate serious

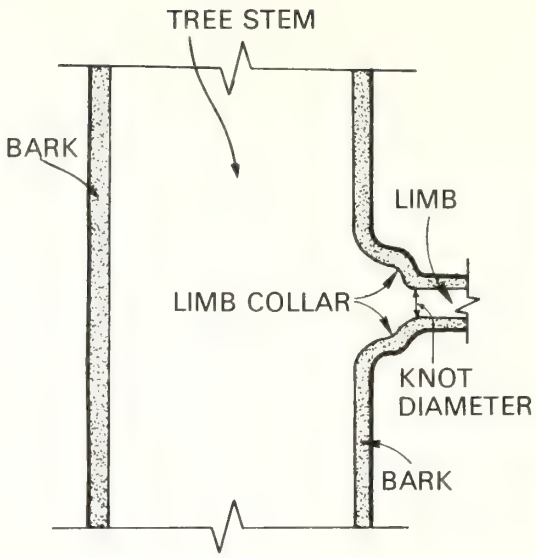

Figure 1.--Schematic drawing of a cross section of a log and limb showing how knot size is determined from measurements (or estimates) of limb diameter inside any limb bark present. Excludes the limb collar or common swelling at juncture with the log surface.

Figure 2.--Numerous dead limbs and stubs (knots) on a Grade IV butt log. This log does not qualify for Grade II for two reasons: (1) it does not have two clear (knot-free) faces, and (2) some of the knots are larger than 2 inches in diameter and cannot be confined to the upper or lower half of one face. The log does not qualify for Grade III because the knots that are larger than 3 inches cannot be confined to one face.

Table 1–A summary of cruising grades for Coast Douglas-fir

<table>
<tr><th>Log characteristic</th><th>Grade I[1/]</th><th>Grade II[1/]</th><th>Grade III[1/]</th><th>Grade IV</th></tr>
<tr><td>Knot (sound)</td><td>One allowed if 1 inch or less
or
one larger than 1 inch if within 6 inches of log end.</td><td>None allowed on two faces. Knots larger than 2 inches must be confined to upper or lower half of one face.</td><td rowspan="2">Knots (sound or rotten) larger than 3 inches must be confined to one face.</td><td rowspan="11">Any merchantable log not meeting requirements for Grade III.</td></tr>
<tr><td>Rotten knot</td><td>None allowed.</td><td>None allowed unless log is otherwise Grade I.</td></tr>
<tr><td>Knot indicator</td><td>If larger than 1 inch, must be confined to no more than two faces.</td><td colspan="2">No requirements.</td></tr>
<tr><td>Knot cluster</td><td>None allowed.</td><td>One if confined to one face.</td><td>Any number if confined to no more than two faces.</td></tr>
<tr><td>Indicator cluster</td><td>One allowed if confined to one face.</td><td colspan="2">No requirements.</td></tr>
<tr><td>Degrading scar</td><td>None allowed from ground line to 8 feet. Above 8 feet: No limit for sound scars 6 inches x 6 inches or smaller; larger sound scars must be confined to either one face or not more than two faces in any one-fourth of log length. No rotten scars allowed.</td><td>All scars having rot must be confined to one face.</td><td>No requirements.</td></tr>
<tr><td rowspan="2">Sound burl[2/]</td><td colspan="3">Disregard burls if less than 6 inches in diameter.</td></tr>
<tr><td>If larger than 6-inch diameter, must be confined to one face.</td><td colspan="2">All larger than 6-inch diameter must be confined to three faces.</td></tr>
<tr><td>Conk, canker, and unsound burl</td><td>None allowed.</td><td>No requirements if log is otherwise Grade I.</td><td>No requirements</td></tr>
<tr><td>Bump and bulge</td><td>None 6 inches x 6 inches or larger allowed from ground line to 8 feet. No requirements above 8 feet.</td><td colspan="2" rowspan="2">No requirements.</td></tr>
<tr><td>Epicormic branches and holes</td><td>Must be confined to one face.</td></tr>
</table>

[1/] A log meeting specifications for either Grade I, II, or III is lowered one grade if adjacent to a cull log.

[2/] When burls are considered, log faces can be shifted from the faces initially established for knots or other characteristics.

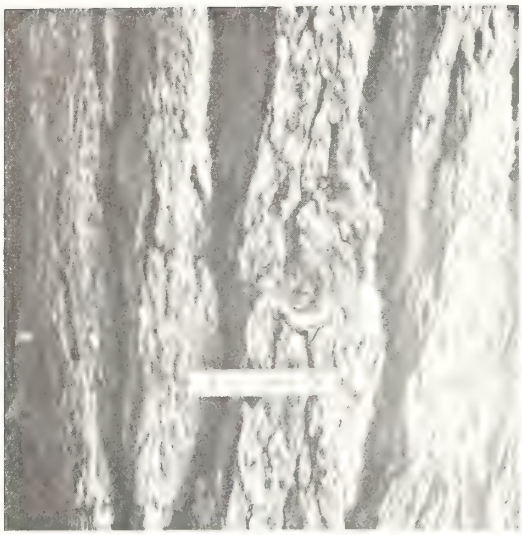

Figure 3.--Knot from dead limb broken off just below log surface, leaving a shallow depression. This is a 1-3/4-inch knot and therefore is not allowed in a Grade I log unless it is the only knot larger than 1 inch on the log and also is located within 6 inches of the log's end. Any number of sound knots less than 2 inches in diameter are allowed on Grade II logs providing the log has two clear (knot-free) faces.

Figure 4.--Typical rotten knots: A, Knot with decay evident on and around the limb stub. This type of knot is permitted on a Grade II log if it is the only knot (live or dead) on the log and, in addition, is within 6 inches of the log end (as it is larger than 1 inch). B, Numerous decaying knots on a Grade IV butt log; knots are exuding black pitch. This log does not qualify for Grade III because there are knots (sound or rotten) larger than 3 inches that cannot be confined to one face.

deterioration in the underlying wood and therefore are not allowed in Grade I logs. They are only permitted in Grade II logs that are otherwise of Grade I quality. In Grade III logs, rotten knots larger than 3 inches in diameter must be confined to one face (table 1).

3. *Knot indicators* are bark distortions that indicate the presence of underlying knots. As knots become overgrown and buried by tree growth, concentric rings or linear breaks in the normal bark pattern may persist for many years. The early stages of the overgrowth may be covered with callous tissue. Many indicators are circular or elliptical with a small depression or hole in the center.

The size of knot indicators is an important grading criterion. Indicators of less than 1 inch in diameter generally mean the underlying knot is so deeply buried that wood product yield will not be significantly affected. Therefore, only knot indicators larger than 1 inch in diameter are considered in grading. Figure 5 illustrates how indicator size is measured. Some examples of typical knot indicators are shown in figures 6 through 8.

Figure 5.--An elliptical knot indicator. Size is determined by the vertical distance across the depression as shown by the arrows. This indicator is slightly larger than 1 inch. All such indicators must be confined to one face on Grade I logs. Indicators, regardless of size or number, are not degrading for Grades II, III, or IV.

Figure 6.--This 2-inch indicator would be allowed in a Grade I log provided it and any others larger than 1 inch were confined to no more than two faces.

Figure 7.--A horizontal break in the bark caused by a former limb that is now a knot indicator. Size is measured vertically (between arrows).

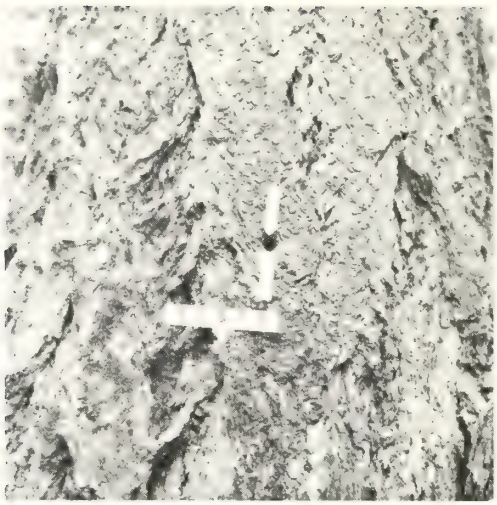

Figure 8.--Typical small indicators less than 1 inch in size. These would be ignored in grading.

4. *Knot clusters* are three or more sound limbs or stubs, all of which are 1 inch or larger, that form a contiguous group (fig. 9). They signify a relatively large and serious defect in the underlying wood. They are not allowed in Grade I logs. One is permitted in a Grade II log if it is confined to one face. In Grade III logs, any number of clusters are allowed *provided* they are confined to no more than two faces.

5. *Indicator clusters* are three or more contiguous knot indicators. They usually form a distinct bark pattern rising above the log surface (fig. 10). One is allowed on a Grade I log if it can be confined to one face. They are not considered defects in Grades II, III, or IV.

Figure 9.--A typical knot cluster with three or more limbs or stubs of 1 inch or larger. Knot clusters are not allowed in Grade I logs. This knot cluster extends into two log faces and therefore would not be allowed in a Grade II log. Any number of clusters are allowed in a Grade III log if confined to no more than two faces.

Figure 10.--A typical indicator cluster. This cluster of indicators is confined to one log face and therefore would be allowed on a Grade I log providing it was the only one on the log. Any number of any size of indicator clusters are permitted in Grades II, III, and IV.

6. *Scars* are the result of injury to the tree stem from such things as fire, logging, frost, lightning, and falling limbs or trees. Scars from recent injuries may show only exposed wood; older wounds may have callous tissue around the edges or be completely overgrown. Overgrown scars often have underlying rot. Pitch is often present in scars. Exposed wood may have checks from weathering and may be stained or show signs of decay. Scars with advanced rot may have a hole or hollow area where the underlying wood has disappeared. Various types of scars are illustrated in figures 11 through 15.

The size, location, and soundness of scars are particularly important for Grade I specifications. In Grade I butt logs no scars are allowed from the ground line to 8 feet up the stem except that an open and shallow scar of recent origin may be considered superficial

Figure 11.--A sound, partially overgrown scar. This would not be allowed in a Grade I log but would be permitted in Grade II even if it had signs of decay because it is confined to one face.

Figure 12.--An overgrown scar that should be assumed to have underlying rot. It would be permitted in a Grade II log as it is confined to one face.

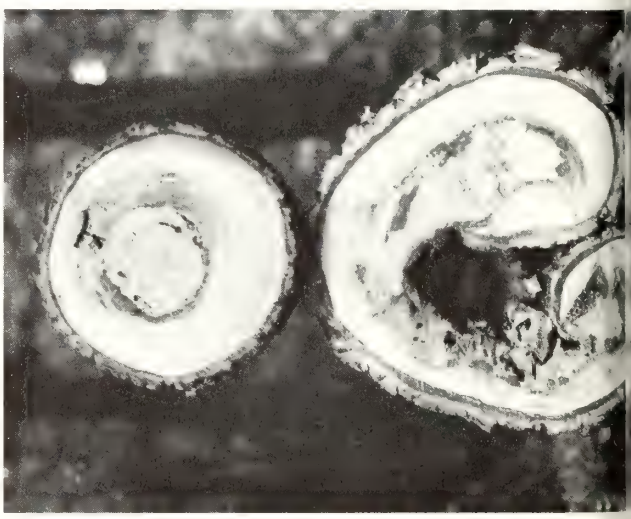

Figure 13.--A, Butt log with partially overgrown scar and void caused by advanced decay; B, cross sections of the same butt log at 3 feet and 10 feet above ground showing interior cavity and decayed wood.

Figure 14.--A long, partially overgrown seam probably caused by lightning. This scar extends in a spiral pattern along the tree stem and cannot be confined to one face. It would not be allowed in a Grade II log.

and be disregarded if, in the judgment of the cruiser, lumber or veneer recovery will not be affected (fig. 16). On sloping ground this 8-foot distance is measured from the uppermost point on the slope (fig. 17). Above 8 feet, any number of sound, small (6 by 6 inches or less) scars are permitted--larger *sound* scars must be confined to either one face or not more than two faces in any one-fourth of the log's length. No scars with decay, regardless of size or location, are permitted in Grade I logs.

For Grade II the only requirement is that scars having decay must be confined to one face. There are no scar criteria for Grades III or IV.

7. *Sound burls* are round or elliptical woody growths that protrude abruptly from the log surface and have no evidence of decay or exuding pitch (figs. 18 and 19). They usually have a broken

Figure 15.--A sound scar, about 8 by 10 inches, near the upper end of the butt log. This type of scar is permitted in Grade I logs if it is confined to one face. If the scar (open and sound) extended into two faces, it would also be allowed in Grade I logs providing it was limited to any one-fourth of the log's length and, if on a butt log, was 8 feet above ground line. Any number of sound scars above 8 feet are permitted in Grade I logs providing they are 6 by 6 inches or smaller.

bark pattern characterized by small, knobby or irregular patches of bark. Their point of attachment is characteristically smaller in diameter than the maximum

Figure 16.--A recent logging scar that would not affect product recovery, particularly since most of it is in the stump area. This scar would be considered superficial and would be disregarded in grading.

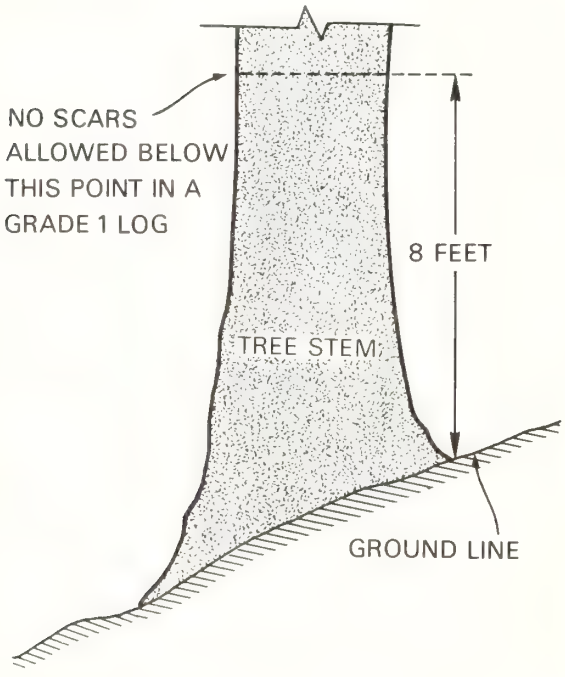

Figure 17.--Schematic drawing of lower section of butt log showing how the limiting 8-foot distance from ground line is measured on trees on a slope. Note that this limiting 8-foot distance extends below the lower end of the butt log to include all of the estimated stump area.

Figure 18.--A sound burl larger than 6 inches that would be permitted in Grade I logs because it is confined to one face.

Figure 19.--A sound burl that would not be permitted in Grade I logs because it is not confined to one face. It would be allowed in Grade II logs because it can be confined to three faces.

diameter of the burl as it extends from the trunk. These characteristics distinguish burls from cankers described in the following section (item 8).

Small, sound burls (less than 6 inches in diameter) are not degrading and should be disregarded. Larger burls generally cause distorted grain in the underlying wood, and therefore, the area they cover is limited for grading. Burls larger than 6 inches in diameter must be confined to one face for Grade I logs. For Grades II and III, all burls larger than 6 inches must be confined to not more than three faces.

Log grading faces can be shifted so that burls are grouped as much as possible. Such shifting of faces is independent of the principal grading faces established on the basis of knots or indicators.

8. *Conks, cankers, and unsound burls* indicate the presence of decay in the interior of a log. These characteristics are not allowed in Grade I logs and are only permitted in Grade II logs that otherwise meet the specifications for Grade I.

Conks are the fruiting bodies of wood-rotting fungi. On the trunks of mature Douglas-fir, the most common conks are caused by *Phellinus pini* (Thore ex Fr.) Pilát (= *Fomes pini*) (fig. 20). Conks of a red brown butt rot are caused by *Phaeolus schweinitzii* (Fr.) Pat. (= *Polyporus schweinitzii*), commonly called velvet top fungi; they may also be found on the roots (fig. 21) or on the lower portion of the butt log but rarely are they found above

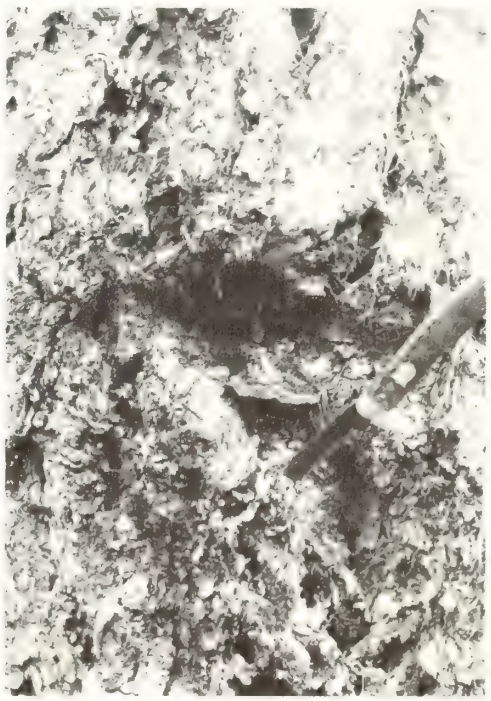

Figure 20.--Conks of Phellinus pini (Thore ex Fr.) Pilát (= Fomes). This is the most common trunk rot of Douglas-fir.

Figure 21.--A typical Phaeolus schweinitzii (Fr.) Pat. (=Polyporus schweinitzii), or "velvet top" conk on the tree root collar. Although it is below the butt log, it is evidence of serious red brown cubical rot extending into the butt log and therefore precludes the log from being Grade I. This butt log would also not qualify for Grade II unless it was otherwise of Grade I quality.

the first 16 feet of the trunk.[2/] *Phaeolus schweinitzii* conks found below the butt log or the stump or on the roots *should be considered as occurring on the butt log*; such a log could not qualify for Grade I and could only be Grade II if it is otherwise of Grade I quality. These specifications for conks do not prevent a cruiser from "culling" a log if, in his judgment, the number and location of conks warrant it.

Cankers are lesions in the bark characterized by swelling and convolutions of callous tissue and pitch. They have sloping edges and a maximum diameter occurring at the base where they protrude from the trunk (fig. 22). They are usually caused by dwarf mistletoe and rusts.

Figure 22.--Typical cankers. Like conks, they are not permitted on Grade I logs and are permitted only on Grade II logs that otherwise meet the specifications for Grade I. They are permitted in Grades III and IV logs.

[2/] Boyce, John Shaw. 1961. Forest Pathology, the American Forestry Series. McGraw-Hill Book Co., New York, Toronto, London.

Unsound burls showing evidence of decay and pitch (fig. 23) are rare on Douglas-fir; when present, they should be considered the same as conks or rotten knots, i.e., they are not allowed on Grade I logs and are allowed only on Grade II logs that are otherwise of Grade I quality. Rotten knots that are swollen and overgrown with knobby bark sometimes have the appearance of unsound burls.

Figure 23.--Unsound burls. They indicate decay in the underlying wood and, like conks and cankers, are not permitted on a Grade I log and are only permitted on a Grade II log that is otherwise of Grade I quality. The grading faces may not be shifted to accommodate unsound burls as they may be for sound burls.

9. *Bumps and bulges* are bark-covered swellings that do not conform to the normal taper in the tree stem or the normal swelling in butt logs (fig. 24). They may occur at any point on the tree stem but are only considered degrading in the butt log. They often indicate decay in the interior of the log. In Grade I logs, no bumps or bulges larger in area than 6 by 6 inches are allowed from ground line to 8 feet up the stem. On sloping ground the 8-foot distance is measured from the uphill side (see fig. 17). Above 8 feet from ground line, all bumps and bulges can be disregarded in grading. These grading rules do not prevent the cruiser from making a log *volume* deduction for a bump or bulge.

Figure 24.--These bumps and bulges are in the lower 8 feet of the tree and therefore are not allowed in Grade I logs. Only bumps or bulges smaller than 6 by 6 inches in area are allowed in this 8-foot section for Grade I logs. There are no bump or bulge requirements for Grades II, III, or IV.

10. *Epicormic branches* are small (less than one-half inch), sprout-type limbs that originate from latent or dormant buds just under the bark. Underlying the epicormic branch or stub is a correspondingly small knot that generally does not extend very far into the wood. The only grading requirement is that they be confined to one face for Grade I logs.

11. *Holes* are defined as the small openings in the bark caused by bird pecking or insect activity (fig. 25). Such activity usually results in stained spots with embedded bark in the underlying wood. Bird pecking is often repeated year after year on the same tree, resulting in layers of overgrown peck spots. Holes are considered degrading only for Grade I logs where they must be confined to one face.

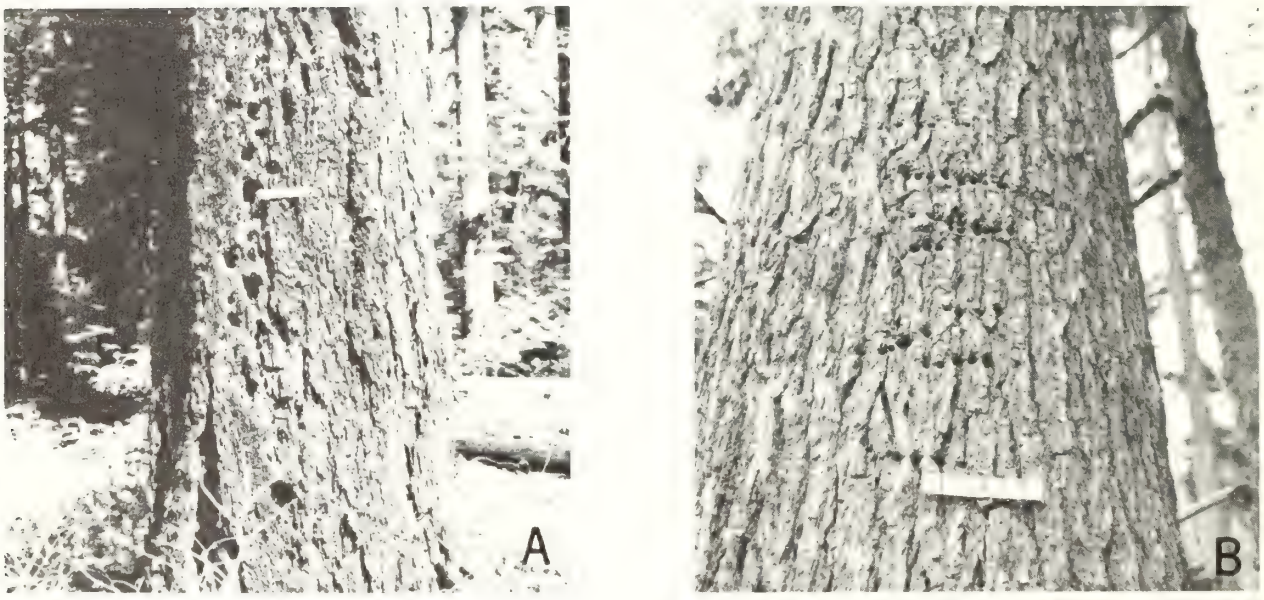

Figure 25.--A, Holes in the bark caused by combined bird and insect activity; B, Typical bird peck holes. In both illustrations, the holes are confined to one log face and, therefore, are permissible in Grade I logs.

Lane, Paul H., and Richard O. Woodfin, Jr.
1977. Guidelines for log grading Coast Douglas-fir. USDA For. Serv. Res. Pap. PNW-218, 14 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

This report is a photographic guide to the application of the new four-grade system for cruising Coast Douglas-fir. It is intended as both a training aid and illustration of features that lower grades.

KEYWORDS: Grading (log), timber cruising, defect indicators (wood quality), Coast Douglas-fir, *Pseudotsuga menziesii*, old-growth stands.

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